GROWTH AND FLOWERING OF *HELICONIA STRICTA* HUBER AND *H. ANGUSTA* VELL.

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ABSTRACT

Plants of Heliconia stricta Huber 'Dwarf Jamaican' at different growth stages (1, 2, and 3 leaves per pseudostem) were treated with three different night temperature (15°, 20° and 25°C) under 8 hr daylength for 4 weeks. Pseudostems with 3 initial leaves and grown at 15°C night temperature had higher inflorescence production than plants with 1 or 2 initial leaves and grown at higher night temperature. The inflorescence production peaked at 19 weeks after the start of short daylength.

Heliconia stricta 'Dwarf Jamaican' Huber. sympodial units in short (9 hr photoperiod) and long (approximately 16 hr photoperiod) daylengths were examined 1 year after planting from a single rhizome piece. An average of 4 generations were produced. The success and failure of sympodial units, their length and their relative angles were studied. The rhizome branching pattern might be hexagonal system. In the first generation, 42.5% of pseudostems grown under shortdaylength flowered while none of pseudostems grown under long daylength flowered. Pseudostem and inflorescence length were significantly longer in LD than in SD and increased with successive generations.

Plants of Heliconia angusta Vell. at different growth stages (1-6 expanded leaves per pseudostem) were grown under 9, 10, 11, 12, and 14 hr photoperiods. The differences in

daylength had no significant effect on the flowering status of pseudostems or average time to flower which was 17 weeks after the start of the daylength treatments.

Apical meristems from plants of Heliconia stricta Huber 'Dwarf Jamaican' growing in short (9 hr photoperiod) or long (approximately 16 hr photoperiod) daylengths at different growth stages (1-6 expanded leaves) were observed. The inflorescence structure was distinguishable in plants under short daylength when pseudostems reached 3 or more expanded leaves while inflorescence structures could not be identified in pseudostems growing in long daylength.

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CHAPTER I
INTRODUCTION

Uses

Heliconias are prized as ornamental plants for landscaping and are an increasing part of Hawaii's cut-flower industry. Heliconia production in Hawaii was first separated out as an individual floriculture crop in 1985 by the Hawaii Agricultural Statistics Service with a wholesale value of $ 125,000 in that year (Haw. Dept. of Ag., 1986). In Florida, heliconias are beginning to be used in interior landscapes because of their green leaves and colorful inflorescences (Ball, 1986).

Botany

Taxonomy

Heliconia is a monotypic genus consisting of about 120-150 species in the family Heliconiaceae in the order Zingiberales (Criley, 1985). Heliconiaceae and Strelitziaceae are often included in Musaceae in the order Zingiberales because of their usually arborescent habit and their flowers with five (or six) pollen-bearing stamens (Dahlgren and Clifford, 1982). Nakai (1941) suggested that

the Heliconiaceae were distinct from the Musaceae and recent studies and publications also accepted this classification (Tomlinson, 1962; Dahlgren and Clifford, 1982; Kress, 1984; Dahlgren et al.,1985).

Habitat

Heliconia is found in nature throughout the New World tropics from the Tropic of Cancer in Central Mexico to the Tropic of Capricorn in South America. Most species inhabit moist or wet regions but some are found in seasonally dry areas. Although heliconias attain their most luxuriant vegetative growth in the humid lowland tropics at elevations below 500 meters, the greatest numbers of species are found in middle-elevation rain and cloud-forest habitats. Few species occur above 2000 meters. Approximately 6 species are found in the Polynesian tropics (Kress, 1984).

Morphology

The family Heliconiaceae is very uniform in its morphology, all its members being herbaceous perennials with sympodially branched rhizomes bearing distichous scale leaves (Tomlinson, 1969). The erect leafy shoots have a distichous leaf arrangement composed of a long basal sheath, long petiole, and expanded, simple, entire blade. The

overlapping basal sheaths form a pseudostem which is more conspicuous than the true aerial stem (Tomlinson 1969; Conquest, 1981). The inflorescence is situated terminally on an erect peduncle and consists of large, flattened thyrse, which is erect or drooping, often with a conspicuously geniculate axis, Each lateral branch is subtended by a stiff, showy, usually boat-shaped bract, which may be broad or narrow, rather small or often quite large, and which is usually brightly coloured (dull green in Asiatic species), red and green, red, orange etc. A dense monochasial cyme, a cincinnus of a few to many flowers, is situated in the axil of each of these bracts, and is sometimes nearly concealed in its axil. The flowers are situated in the axils of floral bracts, which are much smaller and thinner than the cincinnal bracts, being generally pale and membranaceous. The flowers are bisexual, epigynous and strongly zygomorphic. Of the six tepals, the median one in the outer whorl is nearly free from the others which are all fused to form a five-dentate or five-lobe upper lip. The five fused and the one free tepal form a tube. There are five functional stamens and one staminode which is subulate or, to some degree, petaloid. The filaments are free from each other and filiform. The pistil has a trilocular ovary and a narrow, often slightly curved style and on its slightly thickened apex a small, capitate to trilobate papillate stigma. The fruit is a drupe, each

of the three stones of which contains a single seed (Dahlgren et al., 1985).

Heliconia stricta Huber. Plant height is 1.5-4 m tall and inflorescences born 0.5-1.5 m above the ground. The inflorescences are usually 20-30 cm long. The cincinnal bracts have red or orange color on the sides, yellowish on keel and margin, and green on edges. The perianths are white or very pale yellowish. The species is found on the Pacific coast of Ecuador and Colombia north to Valle del Cauca, in the southern parts of the valleys of Rio Cauca and Rio Magdalena, western parts of the Amazon Basin from central Colombia to Bolivia, southern Venezuela, and Suriname. H. stricta grows in a wide variety of habitats such as roadside, swamp and river margins, secondary and virgin rain forest. In open habitats it is mostly gregarious, while the plants are scattered and low-growing in closed forests. Altitudinal records range from near sea level to 1,500 m. (Anderson, 1981). Many different forms have been collected and some selected forms are widely distributed in commercial cultivation as cut flowers. The inflorescence production for H. stricta 'Dwarf Jamaican' has been observed in Hawaii to be year round with peaks in September to March.

Heliconia angusta Vell. A new species name was recently proposed for Heliconia angusta Vell. which previously was named H. angustifolia Hook. The whole plant is about 1 m. high. The cincinnal bracts are bright red to the edge and become darker at maturity. The flowers are white with short glabrous orange-red pedicels. The plant is native to Brazil and was introduced to cultivation about 1848 (Graf, 1982; Baker, 1893). It has also been erroneously confused with H. brasiliensis Peters.. It is likely that more than one form exists. It has a seasonal flowering pattern in Hawaii, peaking in November-December.

Cytology

The basic chromosome number (x) of Heliconia ranges from 8-13, but most commonly x = 12 (Mahanty, 1970, Cronquist, 1981; Dahlgren et al., 1985). Of the 14 species for which chromosome numbers have been reported, fewer than half have legitimate names and several are not identified as to species. It is unlikely that the majority of specimens were identified correctly (Kress, 1984).

Horticulture

Comercial selections

H. humilis Jacq. is most widely used in Southeast Asia, whereas, *H. bihai* L. and *H. caribaea* Lam. are more widely used for cut flowers in Central and South America. Selection has been made for commercial trade with bract color, size, and shape as the main considerations. Bracts of these three species are very showy, colorful and relatively large in size and have thick heavy peduncles. As a result of their large size and weight, they are very costly to transport long distances. A smaller species, *H. psittacorum* L.f., is widely used by the florist trade throughout the tropics because of a good variety of colorful selections and high productivity (Tjia and Sheehan, 1984).

Many *Heliconia* spp. have good potential for interior landscape use. These included *H. latispatha* Benth. X *H. psittacorum* L.f. hybrid 'Golden Torch', *H. psittacorum* L.f. 'Andromeda', dwarf *H. psittacorum* L.f., *H. angusta* Vell. 'Christmas', *H. bihai* L., *H. caribaea* Lam., *H. humilis* Jacq., *H. wagneriana* Peters, *H. rostrata* R. & P., and *H. stricta* Huber 'Dwarf Jamaican' (Ball, 1986).

General culture

Heliconia can be propagated by seeds, division or tissue culture. In tropical countries where natural pollination occurs, heliconias can be propagated by seed (Broschat and Donselman, 1983). The mature seed has a rudimentary embryo and hard seed coat, the combination of which often means a long dormant period. It has been suggested that the seeds should be placed in moist vermiculite or milled sphagnum moss in a plastic bag; held in shady warm conditions until germination activity is observed; and then sown in pots or flats. In Hawaii and elsewhere, the seeds germinate sporadically over a long period, 3 months to 3 years (Criley, 1986b). Generally, the smaller species with erect inflorescences bloom within 1 year, whereas the larger or pendulous flowering types require 2 or more years (Broschat and Donselman, 1983).

Since flower production and postharvest characteristics vary considerably among cultivars, desirable types must be vegetatively propagated. Rhizome division methods suggested by Criley (1986a,b) are as follows: Segments of fleshy rhizome with a 6 to 12 inch portion of the upright pseudostem are cut with a sharp knife. Damaged and dead roots are removed, and old leaf bases and rotted portion of the rhizome are trimmed off. Then the rhizome is dusted with fungicide. The rhizome pieces can be planted directly

in the field or in 1-gallon containers or started in flats of vermiculite. While the pseudostem itself will die, roots will grow from its base and new pseudostems will develop from buds at the base. Root development takes about 4 weeks and activation of the bud 4 to 6 weeks (Criley, 1986a,b).

Tissue culture techniques for some of the commercial species have been developed in Florida but have not been published (Criley, 1986a,b).

In planting heliconia, it is best to loosen the soil and keep it damp in hot areas. In the cooler areas, heliconia grows best in the open sun (Hodge, 1971). Heliconias respond very well to fertilization, with plant vigor, flower size, and productivity positively correlated with fertility level. High nitrogen fertilizers produce rapid growth and flowering (Broschat and Donselman, 1983).

Research

In evaluation and cultural studies in Florida of clones of H. psittacorum and a presumed H. latispatha x H. psittacorum hybrid, it was reported that both species have considerable potential as commercial cut flowers (Broschat et al., 1984a,b). Further, flower production of H. psittacorum increased as nitrogen fertilizer rate was increased and was greater under full sun than under 63% shade (Broschat and Donselman, 1982, 1983). Their

recommended fertilization rate was 650 g N/m^2 yr. By way of fertilize ratio and analysis, they recommended a ratio of 3-1-2 or and analysis of 18-6-12. (Broschat and Donselman, 1983; Broschat, 1986; Criley, 1986a).

Post-harvest life of Heliconia psittacorum cultivars inflorescence averaged 14-15 days in tap or deionized water (Broschat and Donselman, 1983; Broschat, 1986). Tjia and Sheehan (1984) studied the effect of floral preservative on longivity of inflorescence of 3 cultivars of H. psittacorum. The floral preservative used were tap water, deionized water, 8-hydroxy-quinoline citrate (8-HQC), sucrose, ditheothreitol (DTE), silver thiosulfate (STS), and some combination of the above chemicals. They found that all three cultivars did not respond favorably to treatments with floral preservatives. The mature inflorescences lasted 7 days. However bracts lasted longer when harvested at a younger stage.

In Hawaii, Criley and Kawabata (1986) found that H. stricta 'Dwarf Jamaican' showed a seasonal flowering pattern with production higher in winter than in summer. They found that 3 or 4 weeks of short daylength (SD) were of sufficient duration for flower development. The number of expanded leaves at the beginning of SD also affected the response as only 4% of pseudostem with fewer than 3 expanded leaves yielded flowers, while 91% of pseudostem with 4 or more

expanded leaves flowered. Most pseudostems flowered 13 weeks after the start of SD.

Thesis Objective

Most of the literature on heliconias is taxonomic with only a few reports on their culture and management as cut flowers and are only on H. psittacorum. Many physiological and cultural aspects remain to be studied. Plants of H. stricta 'Dwarf Jamaican' and H. angusta were chosen for study because of their interesting seasonal flowering characteristics and the availability of clonal plant material. The objective of this thesis was to determine vegetative and reproductive responses of selected species to temperature and daylength in order to progress towards a goal of controlled flower production.

CHAPTER II

EFFECT OF NIGHT TEMPERATURE ON FLOWERING OF *HELICONIA STRICTA*

Abstract

Plants of *Heliconia stricta* Huber 'Dwarf Jamaican' at different growth stages (1, 2 and 3 leaves per pseudostem) were treated with three night temperatures (15°, 20° and 25°C) under an 8 hr daylength for 4 weeks. Pseudostems of plants grown at 15°C night temperature had the highest percent flowering (55%) while 33% and 10% of plants grown at 20° and 25°C flowered respectively. Pseudostems with 3 initial leaves had the highest percent flowering (60%) while those with 2 and 1 initial leaves yielded 30 and 17 percent flowering respectively. Approximately 19 weeks, after the start of short daylength treatment, were required for development to first anthesis.

Introduction

Heliconia stricta 'Dwarf Jamaican' has been studied in Hawaii since 1979 by Criley and Kawabata (1986). They found that the plant had a seasonal flowering pattern with higher flower production in winter than in summer. Their later experiments showed that *H. stricta* 'Dwarf Jamaican' required

at least 4 weeks of short daylength (SD) to induce inflorescence initiation in pseudostems that had one expanded leaf or less at the start of SD. The leaf number at the start of SD also affected inflorescence production as flower production was very low if there were fewer than three expanded leaves at the start of SD, compared to pseudostems with more than four leaves at the start of SD which had very high flower production. Pseudostems with 4 initial leaves required approximately 13 weeks from the start of SD to anthesis (Criley and Kawabata, 1986).

As the previous study was carried out in ambient temperatures, the effect of night temperature (NT) on inflorescence production of this plant was also of interest. Since this plant originated in tropical Brazil, it was possible that low NT could cause injury to the plant or lead to flower bud abortion. However, H. stricta Huber has been found at altitudes ranging from near sea level to 1,500 m (Anderson, 1981) which might indicate that this plant can produce inflorescences in a wide range of temperatures. Further, this species is also cultivated in south Florida. Studying the range of NT over which it will grow and initiate an inflorescence might help selection of locations for growing this plant for high yields. This experiment was then established to determine the effect of NTs on flowering of H. stricta 'Dwarf Jamaican' by treating the plants at

different NTs. to study the effect of these factors on flower production and development.

Materials and Methods

This experiment was conducted at the Pope Laboratory facility of the University of Hawaii at Manoa. Thirty-six 15-cm pots of uniform 1-year old Heliconia stricta 'Dwarf Jamaican' were selected for the experiment. After all the pseudostems with inflorescences and pseudostems with more than 5 leaves were cut off, only pseudostems with 1, 2 and 3 leaves were used in the experiment. This left 181 pseudostems with an approximate distribution of 5 per pot: 2 with 1 leaf per pot, 3 with 2 leaves per pot and 2 with 3 leaves per pot. Each pseudostem was tagged to identify the initial leaf number. Three groups of 12 pots each, were treated with 8 hr SD, but each group was given a different NT (15°, 20° or 25°C) for 4 weeks from November 25, 1984, to December 23, 1984. There were 59, 64, and 58 pseudostems in 15°, 20° and 25°C NT, respectively. Wheeled carts were moved into three temperature controlled chambers at 4:00 pm and moved out to Pope Lab glasshouse at 8:00 am daily to create 8 hr daylength. The maximum illuminance in the glasshouse was 65 klx. The plants were hand-watered every morning. After SD treatment plants were moved to benches in the glasshouse in which natural daylength varied from 12 to

13 hr from December 23, 1984 to May 6, 1985. The maximum air temperature during this period ranged from 35° to 38°C with a mean of 36.7 °C and night air temperature ranged from 20° to 21 °C with a mean of 20.2°C.

When inflorescences emerged, data were collected at 2 day intervals: date of anthesis of first flower in lowest bract, peduncle and inflorescence lengths, number of cincinnal bracts, and length of each bract measured from base to top along middle of bract. The experiment was terminated on May 6, 1985, 23 weeks after the start of SD treatment. For pseudostems that did not show an inflorescence, a determination of status (vegetative or aborted) was then made by dissecting the stems.

Because there were differences in the total number of pseudostems per pot and number of pseudostems with the same initial leaf number, each pseudostem was then treated as a replication. The analysis of covariance was used to increase precision by removing from the experimental error any variation in the dependent variables associated with the covariate (initial leaf number) and to adjust the treatment means of dependent variables for differences existing in the covariate (Bender et al., 1982). Adjusted treatment mean separation was done with a Duncan's multiple range test where the differences were significant. In analyzing quatitative data such as number of pseudostems in each status (flowered, vegetative or aborted), Chi-Square tests

for independence were used. The null hypothesis in this was that the differences existing among the proportions of observations in each class (flowered, vegetative or aborted) were independent of NT treatments or initial leaf number differences. If the null hypothesis was rejected, percentage of pseudostems in each class were performed Chi-Square test for a fixed ratio hypothesis. The test was done on different pairs of pseudostem percentage within each class. The null hypothesis was that percentage of pseudostems between two different NTs or different initial leaf numbers were not significantly different. This test enabled the separation of percentage of pseudostem in different NTs or initial leaf numbers within a class. The null hypothesis was rejected when the significance probability was less than 0.05 level.

Results

There were 65 inflorescences produced out of a population of 181 pseudostems, and their distribution by temperature were shown in Table 1.

Time to flower

The three NTs and the variation in initial leaf number had no significant effect on time to flower (Appendix

Table 1. Time to anthesis from begining of treatment of *H. stricta* under different night temperatures.

Night temperature (°C)	Inflorescence No.	Days to anthesis (days ± SE)	Weeks to anthesis (wks)
15	34	134 ± 4.9	19.1
20	22	136 ± 6.1	19.3
25	9	132 ± 9.5	18.8
Significance of F value		NS	NS

Table 23). The average time to flower was 134.3 days (Table 1) and peaked at 19 weeks after the start of SD treatment (Figure 1). Pseudostems treated with 15°C or 20°C NTs had a flowering peak at 19 weeks after start of SD while those treated with 25°C NT had a scattered flowering peak because very few inflorescences were produced (Figure 2). Pseudostems with 3 initial leaves had a flowering peak one week earlier than those with 1 or 2 initial leaves (Figure 3).

Pseudostem satus

The NT treatments had a significant effect on percentage of flowering pseudostems and percentage of vegetative pseudostems but did not have a significant effect on percentage of aborted pseudostems (Tables 2). Lowering the NT increased percentage of flowering pseudostems from 17% of pseudostems treated at 25°C NT to 58% of pseudostems treated at 15°C NT. In contrast, at the higher NT, more pseudostems remained in a vegetative stage with 22% at 15°C and 69% at 25°C. There was no significant difference in percent pseudostems aborted for plants in different NT which averaged 18% of the total pseudostems (Table 2, Figure 4).

Initial leaf number also had a significant effect on the proportion of flowering, vegetative and aborted pseudostems (Table 3). Pseudostems with 3 initial leaves

Figure 1. Weekly flower production of H. stricta as a percentage of the total harvest averaged over all NT trts and all initial leaf numbers.

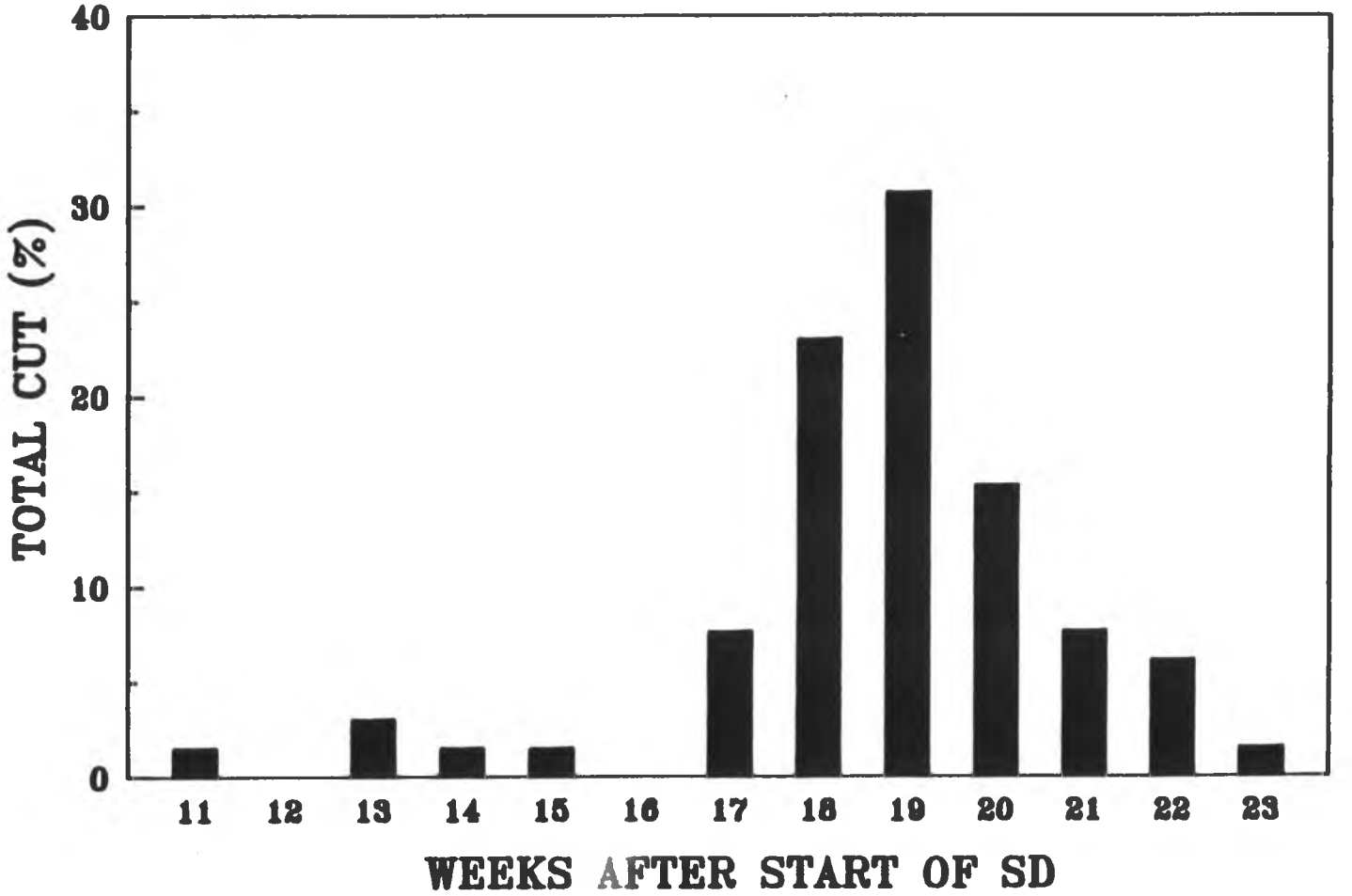


Figure 2. Weekly flower production of H. stricta as a percentage of the total harvest of flowering pseudostems grown at 15°, 20°, and 25°C NT for 4 weeks under SD over all initial leaf numbers.

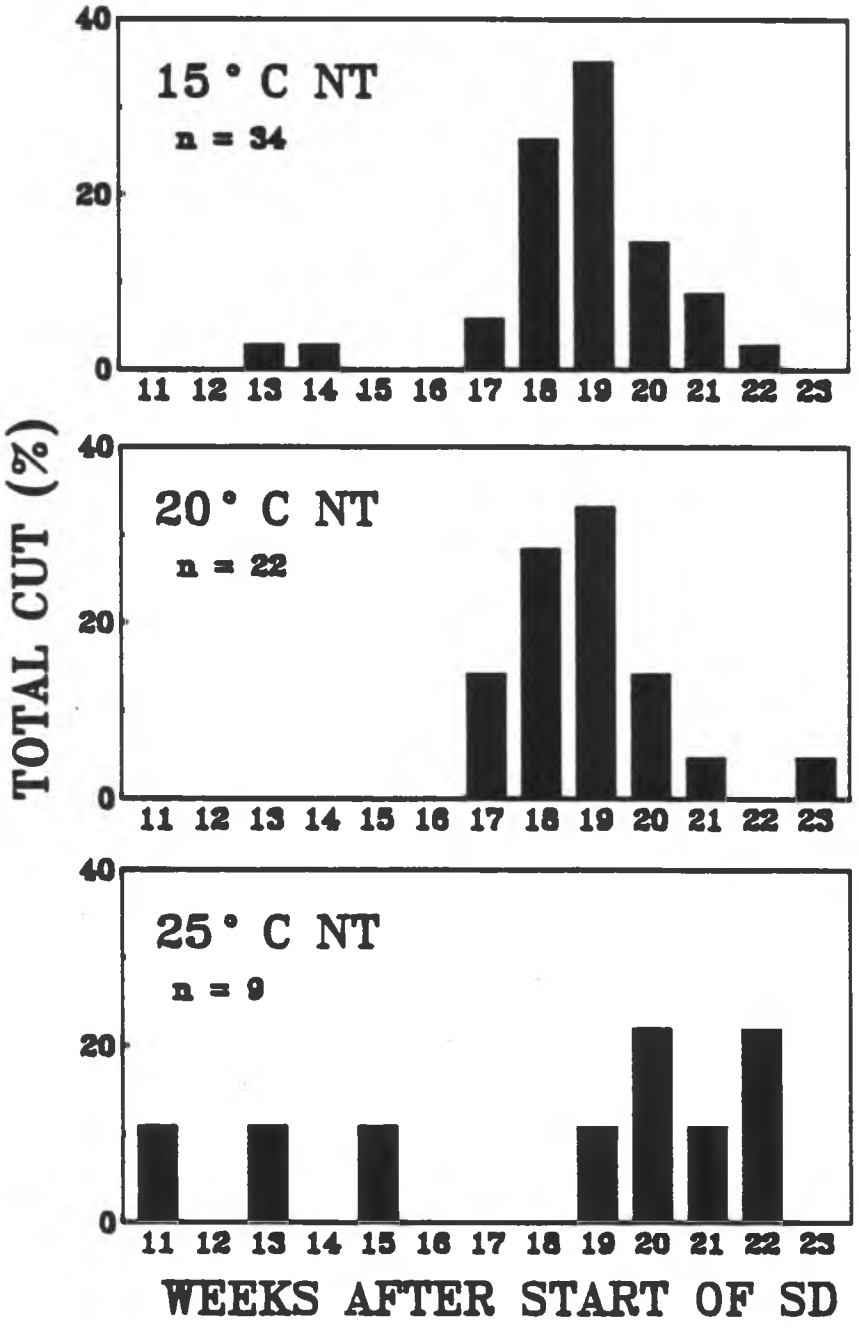


Figure 3. Weekly flower production of H. stricta as a percentage of the total harvest of flowering pseudostems with 1, 2, or 3 initial leaves grown under different NT trts and SD for 4 weeks.

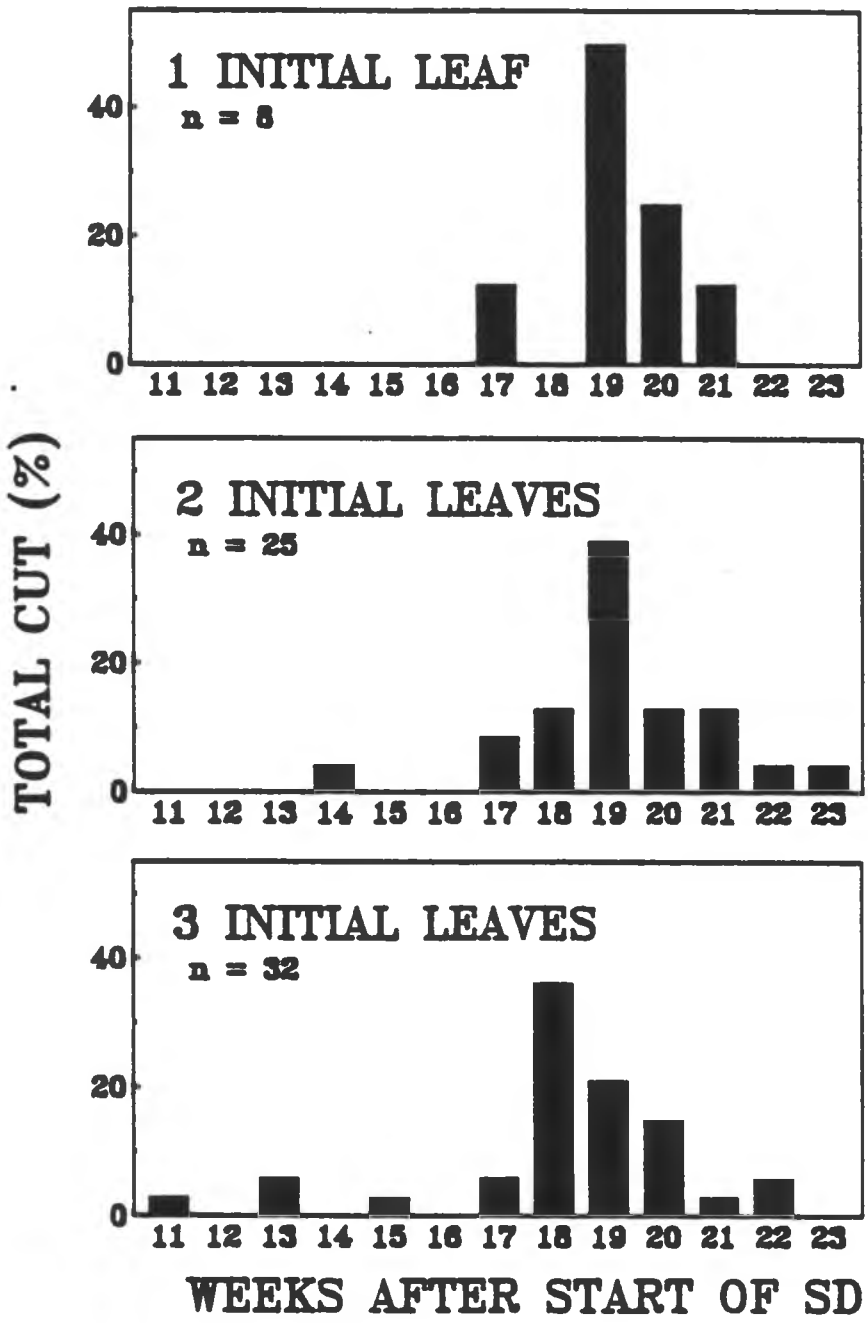


Table 2. Flowering status of H. stricta pseudostems under different night temperatures. The distribution of pseudostems in each status were significantly different among treatments with Chi-square = 28.965 (df = 4),and P = 0.0001.

Night temp. ('C)	Total	Number and (percentage) of pseudostem Flowering	Vegetative	Aborted
15	59	34 (57.6) a[z]	13 (22.0) c	12 (20.3)
20	64	22 (34.3) b	30 (46.8) b	12 (18.7)
25	58	9 (15.5) c	40 (68.9) a	9 (15.5)

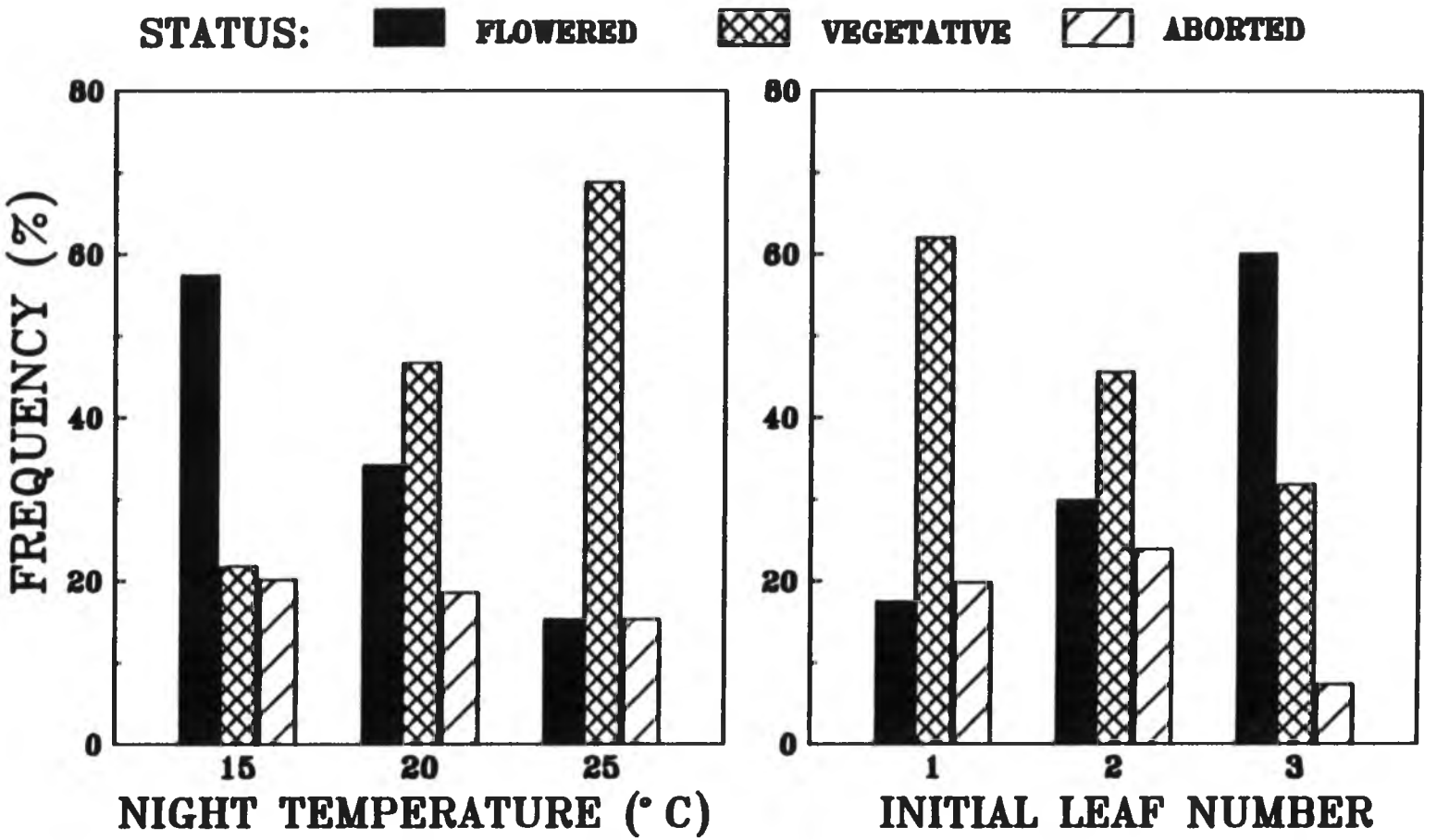
[z]Separation of percentage of pseudostems in each class (column) by Chi-Square.

Table 3. Flowering status of H. stricta pseudostems with different initial leaf numbers. The distribution of pseudostems in each status were significantly different among initial leaf numbers with Chi-square = 23.515 (df = 4), and P = 0.0001.

Initial leaf No.	Number and (percentage) of pseudostem			
	Total	Flowering	Vegetative	Aborted
1	45	8 (17.7) b[z]	28 (62.3) a	9 (20.0) ab
2	83	25 (30.1) b	38 (45.7) ab	20 (24.1) a
3	53	32 (60.3) a	17 (32.0) b	4 (7.5) b

[z]Separation of percentage of pseudostems in each class (column) by Chi-Square.

Figure 4. The percentage of all harvested H. stricta showing vegetative, aborted, or flowering status after treated with SD and 15°, 20°, or 25°C NT for 4 weeks (left); and with 1, 2, or 3 initial leaves over all NT conditions (right).



yielded the highest percent flowering at 60% while those with 2 and 1 initial leaves yielded 30% and 17% of the total pseudostems respectively (Figure 4). In contrast, the lower the initial leaf number the more pseudostems remained in the vegetative stage from 32% with 3 initial leaves to 62% with 1 initial leaf. Also the percentage of aborted pseudostems was higher in pseudostems with 1 or 2 initial leaves (20% and 24%) than those with 3 initial leaves (8%) (Table 3, Figure 4).

When the effect of both NTs and initial leaf numbers was considered, the abortion percentage of pseudostems with 1 initial leaf and grown at 15°C was higher than those with the same leaf number but grown at 20° or 25°C (Figure 5). As a result the flowering percentage of pseudostems with 1 initial leaf number grown at 15°C was lower than those with the same leaf number grown at 20°C (Figure 5).

Number of leaves subtending the inflorescence

There was no effect of NT on number of leaves subtending the inflorescence (Table 4, Appendix Table 24). The average leaf number was 4.9. However the variation in initial leaves had a significant linear component on number of leaves subtending the inflorescence ($P = 0.0217$). The pseudostems with more initial leaves had more subtending

Figure 5. Effects of night temperature and initial leaf number on the percentage of harvested H. stricta showing vegetative, aborted, or flowing status after treated with SD for 4 weeks.

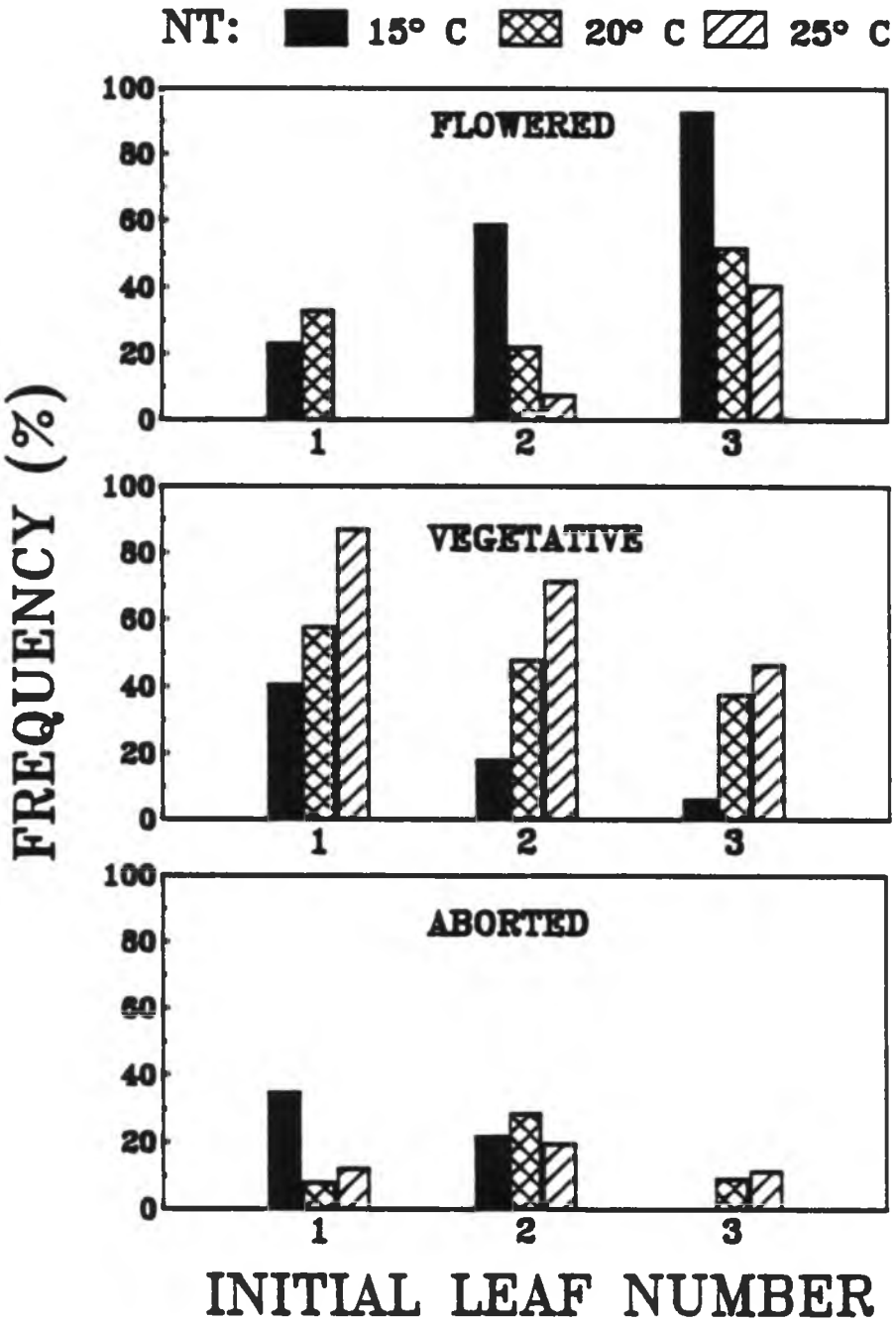


Table 4. Number of leaves subtending inflorescence of *H. stricta* under different night temperatures.

Night temperature (°C)	Number of leaves (± SE)
15	5.0 b[z]
20	5.0 b
25	5.4 a
Significance of F value	0.10

[z]Mean separation in column by Duncan's multiple range test.

leaves than pseudostems which started with fewer leaves with the range from 4.7 to 5.5 leaves.

Inflorescence characteristics

There was a significant effect of NT on length of the inflorescence, peduncle, and inflorescence and peduncle combined (Appendix Tables 25, 26 and 27). Plants treated with 15°C NT had shorter inflorescence and peduncle than those treated with higher NT (Table 5).

NT also had a significant effect on lengths of the first and second bracts (counting from base to tip) but not for the third bract (Appendix Tables 28, 29 and 30). Bract length at each position was longer as the NT increased (Table 6).

There was no significant effect of NT on cincinnal bract number (Appendix Table 31) which averaged 2.3 bracts per inflorescence (Table 6).

Discussion

Criley and Kawabata (1986) showed that from the start of SD to 17 weeks afterward, pseudostems with fewer than 4 initial leaves had very low inflorescence production. In this experiment the inflorescence production of pseudostems with 1 to 3 initial leaves was higher than those in Criley

Table 5. Inflorescence and peduncle length of *H. stricta* under different night temperatures.

Night temperature (°C)	Inflorescence Length (cm ± SE)	Peduncle Length (cm ± SE)	Infl.+Ped. Length (cm ± SE)
15	11.7 b[z]	16.2 b	27.8 b
20	13.1 a	18.2 a	31.3 a
25	13.8 a	18.3 a	32.3 a
Significance of F value	0.002	0.007	0.0001

[z]Mean separation in columns by Duncan's multiple range test.

Table 6. Number and length of cincinnal bracts for *H. stricta* under different night temperatures.

Night Temperature (°C)	Bract Nos.	Length of cincinnal bract (cm)		
		First	Second	Third
15	2.2	11.0 b[z]	7.2 b	5.9
20	2.3	11.1 b	7.4 ab	6.7
25	2.3	12.0 a	8.0 a	6.9
Significance of F value	NS	0.0006	0.023	NS

[z]Mean separation in columns by Duncan's multiple range test.

and Kawabata's (1986) experiment. However the number of weeks to anthesis in this experiment was greater than in the previous study (Criley and Kawabata, 1986). This might be explained as follows:

a) Since the pseudostem seems to require a certain number of leaves before flowering, the shorter time to flower might reflect the fewer number of leaves that need to develop when a large number are already developed.

b) The Criley and Kawabata (1986) experiment was conducted in September while this experiment was done in November. The difference in the time of the year might reflect lower temperatures and solar radiation in this experiment compared to the Criley and Kawabata (1986) study. These might cause a decrease in the rate of inflorescence development.

c) Plant materials in the Criley and Kawabata were grown in a larger container (25-cm tubs) than those in this experiment (15-cm tubs). Plants grown in larger container might have more food reserves in the rhizome to support inflorescences development than those in small containers.

d) The increasing sensitivity of the plant to a floral stimulus as increase in leaf area that permits perception of the stimulus.

We may conclude that pseudostems with 4 or more initial leaf number tend to produce the inflorescence sooner than those with fewer initial leaves which is in agreement with an experiment reported on wheat by Caddle and Weibel (1972).

The apical meristems of pseudostems with 1 leaf might have less protection against chilling because there was less basal sheath covered and the sheath was still soft and young. NT at 15°C then might cause chilling injury to the apical meristem and later cause abortion. However overall percentages of flowered, vegetative and aborted pseudostem with different initial leaf number in this experiment confirmed the results of the Criley and Kawabata (1986) experiment. The percentage of flowered pseudostems was higher as the initial leaf number was higher. Comparing percent flowering of pseudostem with 3 initial leaves in this experiment with the Criley and Kawabata (1986) experiment, the flowering percentages of pseudostem treated at 25°C and 20°C in this experiment ranged from 30% to 52% (Figure 5). Correspondingly, Criley and Kawabata (1986) experiment showed the flowering percentage of 45% at NT around 21°-23°C, which was in the same range as in this experiment. The flowering percentages of pseudostems with 1 and 2 initial leaves in the previous experiment were very low. However the flowering percentage of the pseudostems in the previous experiment might have increased if the natural-day observation period had been extended to 19 or 20 weeks

to allow development of pseudostems with fewer leaves at the start of SD.

Length of inflorescence, peduncle and number of bracts in this experiment were inferior to those in the Criley and Kawabata (1986) experiments. This may be due to plant material in the previous experiment being more vigorous because it was grown in a larger container (25 cm tubs) while plants in this experiment were grown in 15 cm pots

This experiment and the Criley and Kawabata (1986) experiments indicate that Heliconia stricta 'Dwarf Jaimaican' inflorescence can be induced on pseudostem at the stage of 1 expanded leaf by 8 hr daylength but the percent flowering was low with only 1 or 2 initial leaves. At 15°C NT 93% of the pseudostems with 3 initial leaves flowered. Approximately 5 more weeks was required from the start of SD treatment to first anthesis in this experiment than the Criley and Kawabata (1986) experiments. SD treatment to 4 or more leaf pseudostems resulted in very high flowering percentage (Criley and Kawabata, 1984) without low NT treatment.

CHAPTER III

GROWTH AND FLOWERING OF *HELICONIA STRICTA* UNDER DIFFERENT DAYLENGTHS

Abstract

Heliconia stricta 'Dwarf Jamaican' Huber. sympodial units in short (9 hr photoperiod) and long (approximately 16 hr photoperiod) daylengths were examined 1 year after planted from a single rhizome piece. An average of 4 generations were produced. The success and failure of sympodial units, their length and their relative angles were studied. The rhizome branching pattern might be hexagonal system. In the first generation, 42.5% of pseudostems grown under shortdaylength flowered while none of pseudostems grown under long daylength flowered. Pseudostem and inflorescence length were significantly longer in LD than in SD and increased with successive generations.

Introduction

The few studies conducted on *Heliconia stricta* Huber. 'Dwarf Jamaican' in Hawaii were related to production and photoperiod (Criley and Kawabata, 1986). Studies of *Alpinia speciosa* L. predicted the branching pattern of rhizomes by using a computer program called 'RHIZOM' (Bell, 1976, 1979;

Bell and Tomlinson, 1980; Bell et al., 1979). Shah and Raju (1975) also studied the rhizome morphology and pattern of Zingiber officinale Rosc.

The underground stem and rhizome pattern was studied in the following experiment as a first step for predicting production yield and coverage area of the plant in a particular period of time. Since ginger and heliconia have quite similar growth patterns, the methodology for the following study was derived from the above studies; however no attempt was made to simulate a branching program by computer. Two different photoperiods (short daylength and long daylength) were incorporated to study their effects on flowering and growth of the plant.

Morphology of H. stricta 'Dwarf Jamaican'

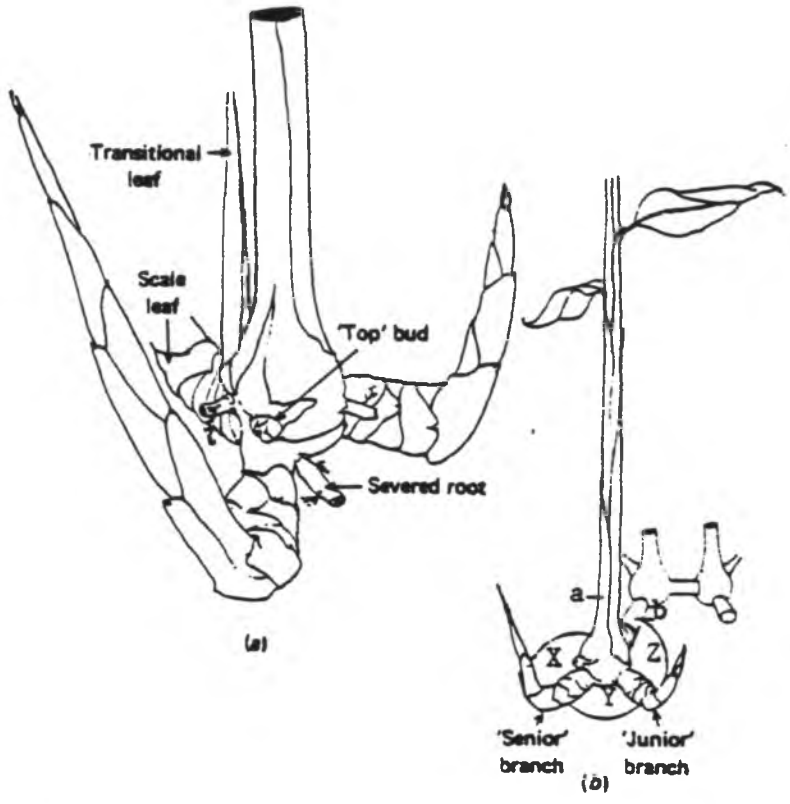
H. stricta 'Dwarf Jamaican' has an aerial pseudostem that normally grows to 0.5 m or more, bearing 6 foliage leaves and a terminal inflorescence. Each aerial pseudostem is the distal orthotropic extension of a unit of the sympodial rhizome system. Each sympodial unit bears a number of scale leaves along its horizontal length and a number of transitional leaves at or just above ground level before forming full-sized foliage leaves. Conspicuous buds are borne in the axils of the first five of the transition leaves, and it is the proximal pair of these buds which

normally have the potential to develop into daughter sympodial units (Figure 6). As the distichously arranged scale leaves are oriented to left and right, the developing buds are similarly arranged. The more proximal of the pair is referred to in this paper as the 'senior' bud, and the more distal is the 'junior' bud. The distal dormant buds are referred to as the 'top' buds.

Materials and Methods

One hundred and twenty rhizome pieces of Heliconia stricta 'Dwarf Jamaican' were potted singly in 15-cm pots on June 20, 1985 in a greenhouse at the Magoon greenhouse facility of the University of Hawaii. The potting medium was a mixture of peat and perlite 1:1 ratio (V/V) and amended with dolomite, Micromax and treble superphosphate at the rates of 6.0, 1.0 and 0.6 kg per cubic meter, respectively. One-half of the pots were given 9-hr photoperiod (SD) using an automatic black cloth shading system from 5:00 pm to 8:00 am. The other 60 pots were given LD by supplementing natural daylength with incandescent illumination from 6:00 pm to 10:00 pm with 60-W lamps placed 1.3 m above the pots to give approximately 16 hr daylength (LD). After new shoots appeared which took approximately 6 weeks, 30 pots of Heliconia in each daylength were selected. The experiment was conducted as a

Figure 6. H. stricta 'Dwarf Jamaican' a) The base of a single aerial shoot showing the development of the two daughter pseudostems, and a top bud. b) One sympodial unit is indicated consisting of 'a' the aerial portion and 'b' the rhizome portion; and angle 'Y' between daughter branches, 'X' proximal stem and left hand daughter, and 'Z' proximal stem and right hand daughters (Source: Bell, 1979).



completely randomized design with each pseudostem as an experimental unit. Plants were drip irrigated twice daily with nutrient solution, 200N-0P-500K (ppm), at the rate of 1000 ml per pot per day.

After one year (June 25, 1986) the daylength treatments were terminated. The average maximum daytime air temperatures during: June to September, 1985; October to November, 1985; December, 1985, to January, 1986; February to March, 1986; and April to June, 1986 were 38°, 34°, 32° 35° and 37°C respectively. The average night air temperatures during: June to October, 1985; November, 1985 to April, 1986; and May to June, 1986 were 23°, 20° and 23°C respectively. The maximum illuminance in the greenhouse was 71 klx.

The plants from each daylength were removed from the pots to study the rhizome morphology. The growing medium was removed by a high pressure water jet, and roots were cut off. The following data were recorded for each pot or sympodial unit:

a. The number of sympodial units per pot.
b. The generation number of each sympodial unit.
c. The length of each sympodial unit measured from pseudostem center to pseudostem center.
d. The number of scale leaves from the first scale leaf of the lateral branch to the scale leaf subtending the senior daughter branch inclusively.

e. The status (senior or junior) and the orientation (to the left or to the right of the parent shoot) of each unit.

f. The three angles of each 'Y' junction measured by holding a transparent plastic protractor above the angle. These angles are expressed as 'triplets' as in Figure 6.

g. The developmental status of each aerial shoot in terms of four categories: Juvenile (including 1 or more nonexpanded leaves); vegetative; flowering; dead.

h. The height of each aerial shoot which consisted of the length of basal sheath, petiole and the length of the expanding leaves.

i. The number of cincinnal bracts, length of petiole measured from the scale leaf subtending the senior daughter branch to the base of the first bract, and the length of inflorescence measured from the base of the first bract to the apex of the last bract.

In this experiment, photoperiods were the primary treatments, but generation which occurred during treatment over a period of time was also considered a source of variation. The analysis of covariance was also applied to this experiment by including generation number in the model as a covariate. When the covariate is measured after the treatments have been applied, it is important to determine

if the behavior of the covariate is substantially influenced by the treatments applied. If the treatments significantly affect the covariate, the use of the covariance analysis takes on a different role, instead of being used to reduce experimental error, it is now used to assist in the interpretation and characterization of the treatment effects upon the character of interest in much the same way that regression and correlation analyses are used (Gomez and Gomez, 1976).

To analyze quantitative data such as number of juvenile, vegetative, flowering or dead pseudostems, Chi-Square tests for independence were used. The null hypothesis in this was that the differences existing among the proportions of observations in each class (juvenile, flowered, vegetative or dead) were independent of daylength treatments or generation differences. If the null hypothesis was rejected, percentage of pseudostems in each class were performed Chi-Square test for a fixed ratio hypothesis. The test was done on different pairs of pseudostem percentage within each class. The null hypothesis was that percentage of pseudostems between two different daylength or different generation were not significantly different. This test enabled the separation of percentage of pseudostem in different daylength treatments or generations within a class. The null

hypothesis was rejected when the significance probability was less than 0.05 level.

Results and Discussion

The results of: length of sympodial unit, scale leaf number, branching angle, orientation of daughter branch and success rate of daughters, would provide basic information for simulating a growth pattern of H. stricta 'Dwarf Jamaican' growing in different daylengths. The scale leaf numbers indicated how consistent the rhizome system would be in successive generations. The sympodial unit length together with branching angle would provide information on how much more the coverage area would be in successive generations. The orientation of daughter branches indicated how the branching pattern would be if the senior daughter consistently developed on the opposite side of its parent, it would result in the straight line zig-zag branching system. The success percentage of daughters would indicate how many new sympodial units would be produced in the successive generation. By combining these data together a simulation of H. stricta 'Dwarf Jamaican' growth pattern could be developed.

There were 815 pseudostems produced from 60 single rhizome pieces during a period of one year with the maximum of 5 generations produced from each rhizome piece. There

were significantly more generations produced from plants grown in LD than those in SD (Table 7, Appendix Table 32). However the average number of generations per pot of both plants grown under SD and LD was close to 4. The time period from the emergence of one generation to the next one was not included in this experiment. The average of 4 generations produced per year or approximately 3 months per generation might be estimable. However there might be differences in development periods among generations.

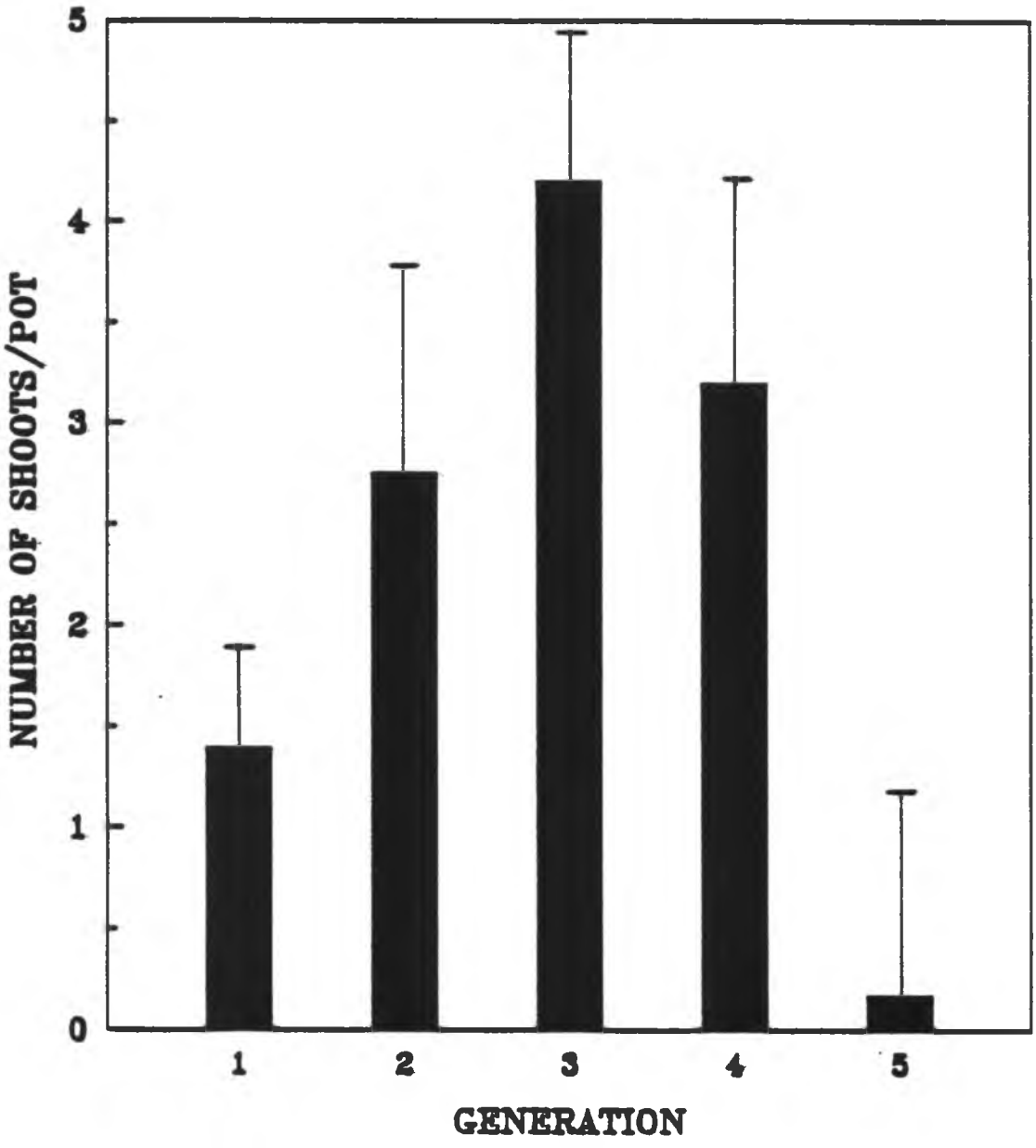
Pseudostem number in each pot consisted of pseudostems that developed from senior and junior buds and pseudostems that developed from top buds.

The 10.8 pseudostems/pot in SD and 12.7 pseudostems/pot in LD were not significantly different between different daylength at the 5% level (Table 7, Appendix Table 33). However the distribution of pseudostems among different generations created a curvi-linear pattern (Figure 7) which peaked in the third generation. In generations 1, 2, and 3 most of the buds had already developed either into pseudostems or aborted so that the number of pseudostems in each of these generations was at or near its potential maximum, while in generation 4 and 5 most of the buds had just developed or were still dormant so that the number of pseudostems in the last two generation was lower than expected (higher than in the third generation). The importance of this is that the third generation was just

Table 7. Number of generations and number of pseudostems for *H. stricta* under different daylengths.

Photoperiod	No. of pots	Generations (Number/pot ± SE)	Pseudostems (Number/pot ± SE)
9 hr daylength	30	3.8 ± 0.3	10.8 ± 1.4
16 hr daylength	30	4.2 ± 0.3	12.7 ± 1.4
Significance of F value		< 0.01	NS

Figure 7. Number of pseudostems of H. stricta for different generations averaged over SD and LD for a period of 1 yr.



reaching a maturity climax one year after the rhizomes were planted.

The number of pseudostems developing from the top buds was not significantly different at the 5% level between the two daylengths: 4.1 pseudostems/pot in SD and 5.5 pseudostems/pot in LD. Generation did not affect pseudostem number of top buds (Appendix Table 34).

Scale leaf number

Daylength had no significant effect on the number of scale leaves which averaged 5.1 scales per sympodial unit (Table 8, Appendix Table 35). The effect of generation had a highly significant linear component at the 1% level on the scale leaf number. The scale number in the first generation varied from 5 to 10 leaves with an average of 5.6 leaves but other generations had an average of 5 leaves.

Sympodial unit length

The sympodial units of plants under LD treatment averaged 2.5 cm which was significantly longer than the 2.3 cm for those under SD at 1% level (Table 8, Appendix Table 36). Both generation and generation x daylength interaction had a highly significant linear effect on sympodial unit length at the 1% level. Sympodial units in the first

Table 8. Number of scale leaves on rhizome portions and length of rhizomes for *H. stricta* under different daylengths.

Photoperiod	Length of rhizome (cm ± SE)	No. of scale (± SE)
9 hr daylengt	2.3 ± 0.07	5.1 ± 0.04
16 hr daylength	2.5 ± 0.02	5.0 ± 0.04
Significance of F value	0.0001	NS

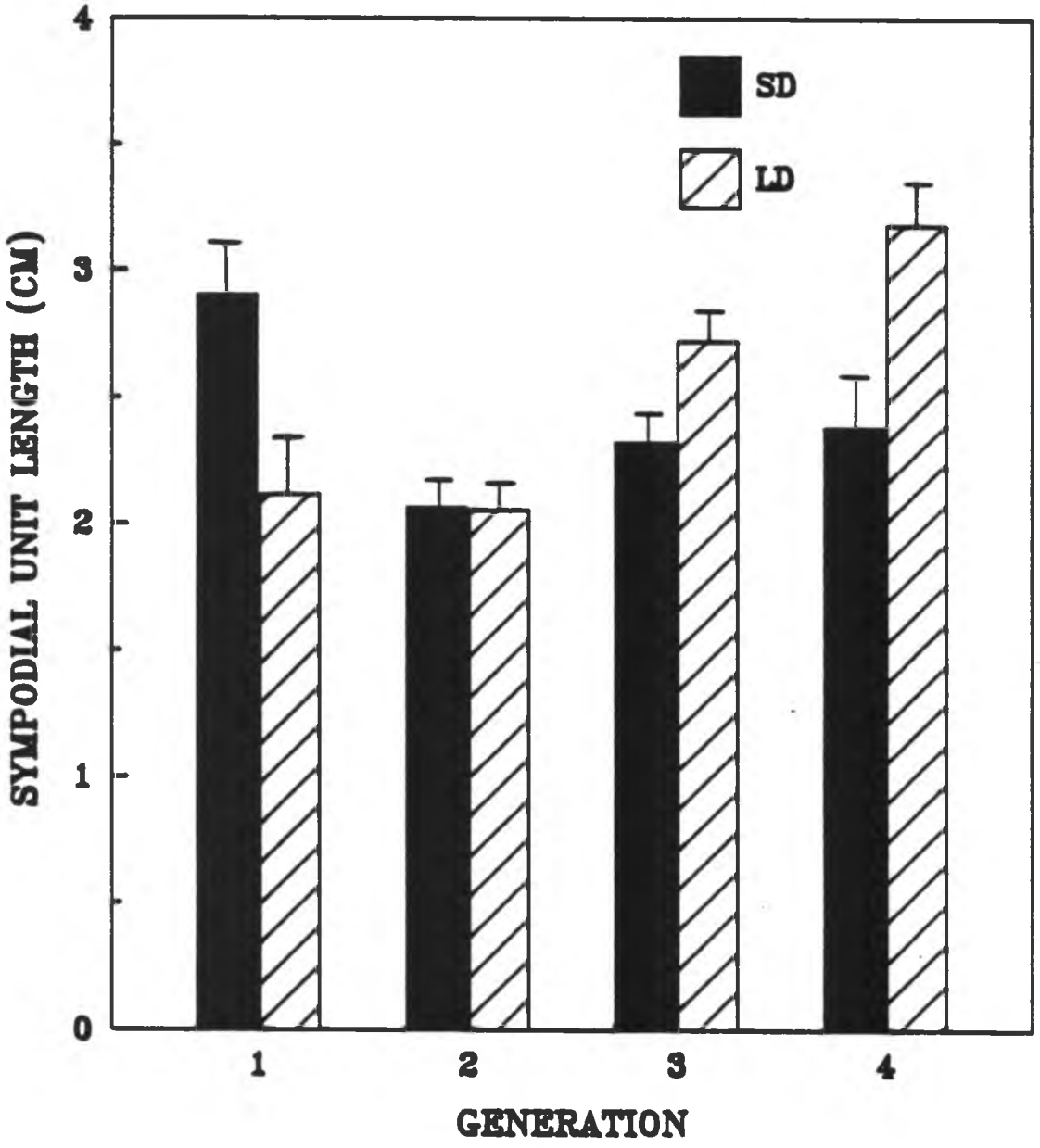
generation were longer than those in the second generation only for SD. They were the same for LD in generation 1 and 2. From the second generation on the sympodial unit length increased for both daylength treatments in successive generations (Figure 8).

The larger number of scale leaves and longer sympodial units in the first generation when compared to the second generation might have been an effect of the rhizomes being planted too deep. The underground portion of the sympodial units in the first generation may have elongated towards the medium surface with a concomitant increase of the number and the length of the scale leaves. In later generations when the rhizome unit was closer to the medium surface the scale leaf number was more constant. However, sympodial unit length increased with successive generations, probably reflecting the fact that more pseudostems were produced bearing more leaves for photosynthesis and more nutrient could be stored in the rhizome to support more vigorous sympodial units.

Branching angle

The initial assumption was that all angles approximated the 'perfect' triplet of a hexagonal grid system (120°/120°/120°). However the result showed that the

Figure 8. Lengths of sympodial units by generation for H. stricta rhizomes grown in SD or LD.



average central angle was 127.0° (Table 9). Daylength had no significant effect on the angle at 5% level but generation had a significant linear effect on the central angle at 5% level (Appendix Table 37). The central angle (Y) decreased toward 120° in the youngest generation (Figure 9). An examination of the raw data showed that there was a large group of central angle with 180° in the first generation which might be the effect of the depth or orientation of rhizome pieces when first planted. When rhizome progressed to near the soil level in subsequent generations the central angle was more constant at 120°. This was tested by analysis of variance of the central angle without the first generation. The results showed no significant effect of generation on the central angle at 5% level (Appendix Table 38). The two side angles (X and Z) were not significantly different at 5% level ($t_{0.05}$ = 0.28^{NS}, df = 632) as the mean of X was 117.3° and the mean of Y was 117.0°.

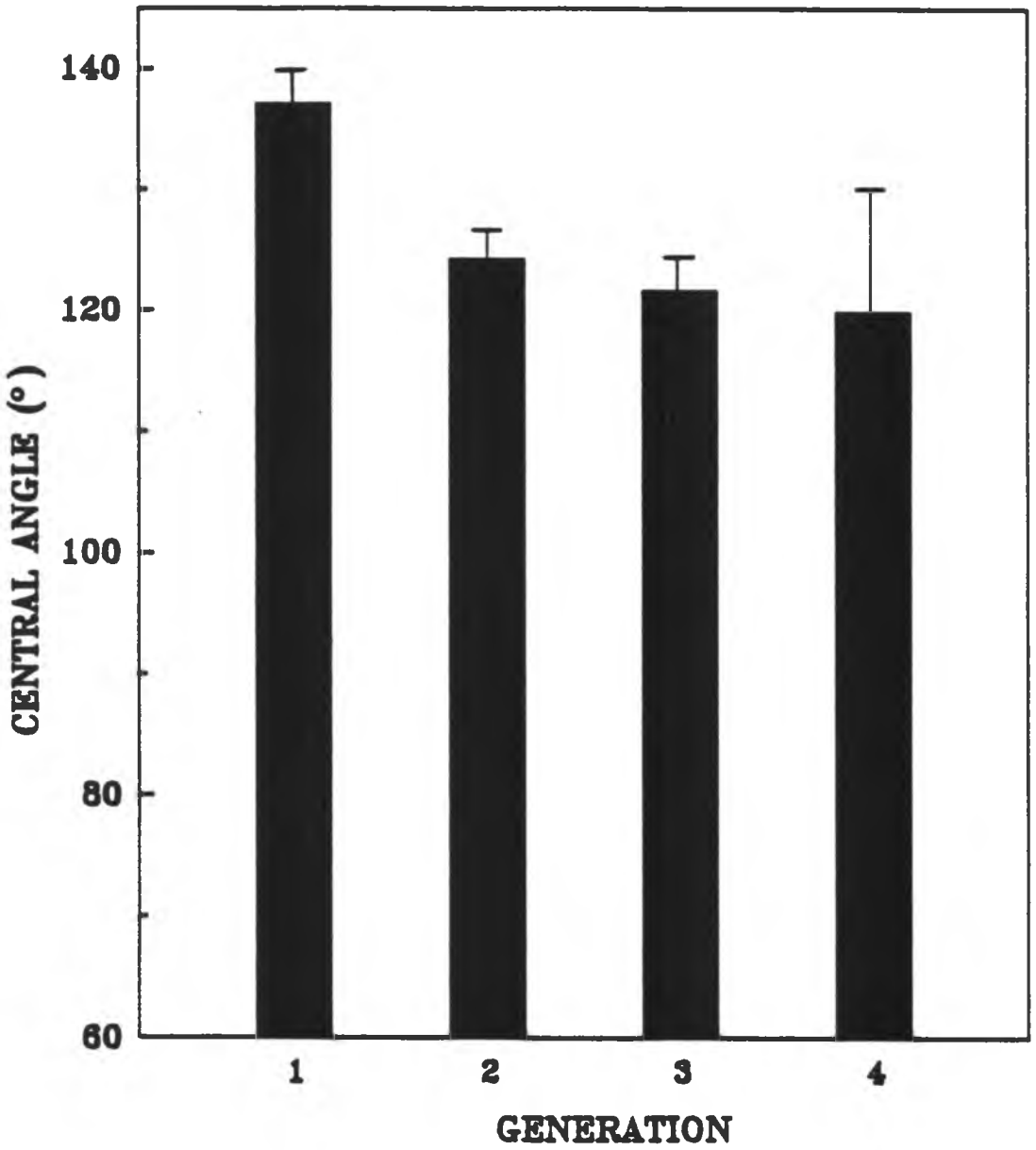
Orientation of daughter sympodial unit

As the senior branch was not consistently on the opposite side to its parent, then the chances of senior branch orientation to the right or the left of the parent should be equal. First, percent of the senior oriented to the left in different daylength and generation was tested

Table 9. Branching angle: X and Z - side angle, Y - central angle for H. stricta rhizomes under different daylengths.

Photoperiod	X	Y	Z
	(degree ± SE)		
9 hr daylength	116.2	127.6	117.5
16 hr daylength	116.1	126.6	117.1
Significance of F value	NS	NS	NS

Figure 9. Central angle between daughter pseudostems by generation for H. stricta rhizome averaged over both SD and LD.



and showed no significant effect of either factor at 5% level (Appendix Table 39). Percent senior oriented to the left of the parent shoot in SD was 49.1% and those in LD was 43.9%. Numbers two-sided (left and right) shoots in each pot were not significantly different at 5% level ($t_{0.05}$ = 0.334^{NS}, df = 114) at 5% level. There was an average of 3.3 shoots oriented to the right side and an average of 2.9 shoots oriented to the left per pot. The results then supported the hypothesis that there was no difference in number of pseudostems oriented to the left or the right of the parent.

Success rate of daughters

Under normal conditions sympodial units either developed fully, becoming orthotropic at the distal end and produce foliage leaves, or aborted before forming daughter branches. Correspondingly, sympodial units may be described in term of success or failure. A 100% success rate would reflect the potential of both of a sympodial unit to develop and grow. Four categories were designated to represent the success of the senior shoot, both shoots, junior shoot and neither shoot.

Because most of the buds in generation 4 and 5 were at early developing stages, only shoots in generation 1, 2 and 3 were considered for calculating the success rate.

The numbers of pseudostems in each category were presented in Tables 10 and 11 by photoperiods or generations. There were no differences in the number of pseudostem produced in SD or LD (Table 10). The increase in pseudostem number was mostly dependent on the success rate of the junior buds because the senior buds already had high success rate. The low success rate for junior buds of the newly planted rhizome pieces might be due to utilization of nutrients stored in the rhizome to produce roots and stimulate the senior buds so that not much nutrient was left in the rhizome for junior bud development. The success rate for junior buds of the second generation pseudostems was lower than those of the first generation. This was probably due to fact that some buds were still young and not fully developed. However, it was possible that in the later generations there were more competition for light, nutrients and space which resulted in fewer daughter bud development. The average percent increase of pseudostems in the preceding generation was 57.4% (Table 11). However the number should be interpreted with caution since the percentage was not consistent among the generations.

Pseudostem final status

Pseudostems grown under LD had higher juvenile and flowering percentages than those grown under SD (Tables 12).

Table 10. Number of senior or junior daughter units developed under different daylengths for H. stricta.

Trt.	No. of daugther units developed				Total
	Both	Senior	Junior	Neither	
SD	93 x 2	42	7	2	235
LD	94 x 2	40	3	3	231

Table 11. Number of daughter units developed and percent increase of pseudostem number (senior or junior) in different generations for H. stricta.

Gen.	No. of daugther units developed					
	Both	Senior	Junior	Neither	Total	%Increase
Start					60	
						38.3%
1	23 x 2	35	2	0	83	
						88.0%
2	74 x 2	3	5	1	156	
						45.5%
3	90 x 2	44	3	4	227	
					Average	57.3%

Table 12. Flowering status of *H. stricta* pseudostems under different daylengths. The distribution of pseudostems in each status were significantly different among treatments with Chi-square = 11.239 (df = 3), and P = 0.01.

		Number and (percentage) of pseudostem			
Trt.	Total	Juvenile	Vegetative	Flowered	Dead
SD	319	41 (12.8)	212 (66.5)	36 (11.3)	8 (2.5)
LD	377	69 (18.3)	206 (54.6)	64 (17.0)	8 (2.1)

However pseudostems grown in SD had higher percentage of vegetative pseudostems than those in LD. There were no differences in among percentage of dead pseudostem between the two photoperiod condition (Figure 10).

There were significant differences in the distribution of the final status in different generations (Tables 13). The percentage of juvenile pseudostems was highest in the fifth generation and decrease to 0 in the first generation. Conversely, the percentage of dead pseudostem which was significant in the first generation and decreased to 0 in the forth generation (Figure 11). The percentage of flowered pseudostems was higher in the first generation than those in the second and third generation. No inflorescences were produced in the forth or fifth generations. The percentage of vegetative pseudostems peaked in the second generation but decreased in the first and the successive generation.

Considering the photoperiod x generation interaction, the flowering percentage of pseudostems grown in SD was 42.5% in the first generation and decreased sharply to 7% and 10% in the second and the third generation. The pseudostems grown under LD had higher flowering percentages than those under SD in the second and third generation but they did not flower in the first generation (Figure 12).

The distribution of pseudostems with different leaf numbers in different generations showed that first

Figure 10. The percentage of all H. stricta pseudostems showing juvenile, vegetative, flowered and dead status after 1 year of growth in SD or LD averaged over 5 generations.

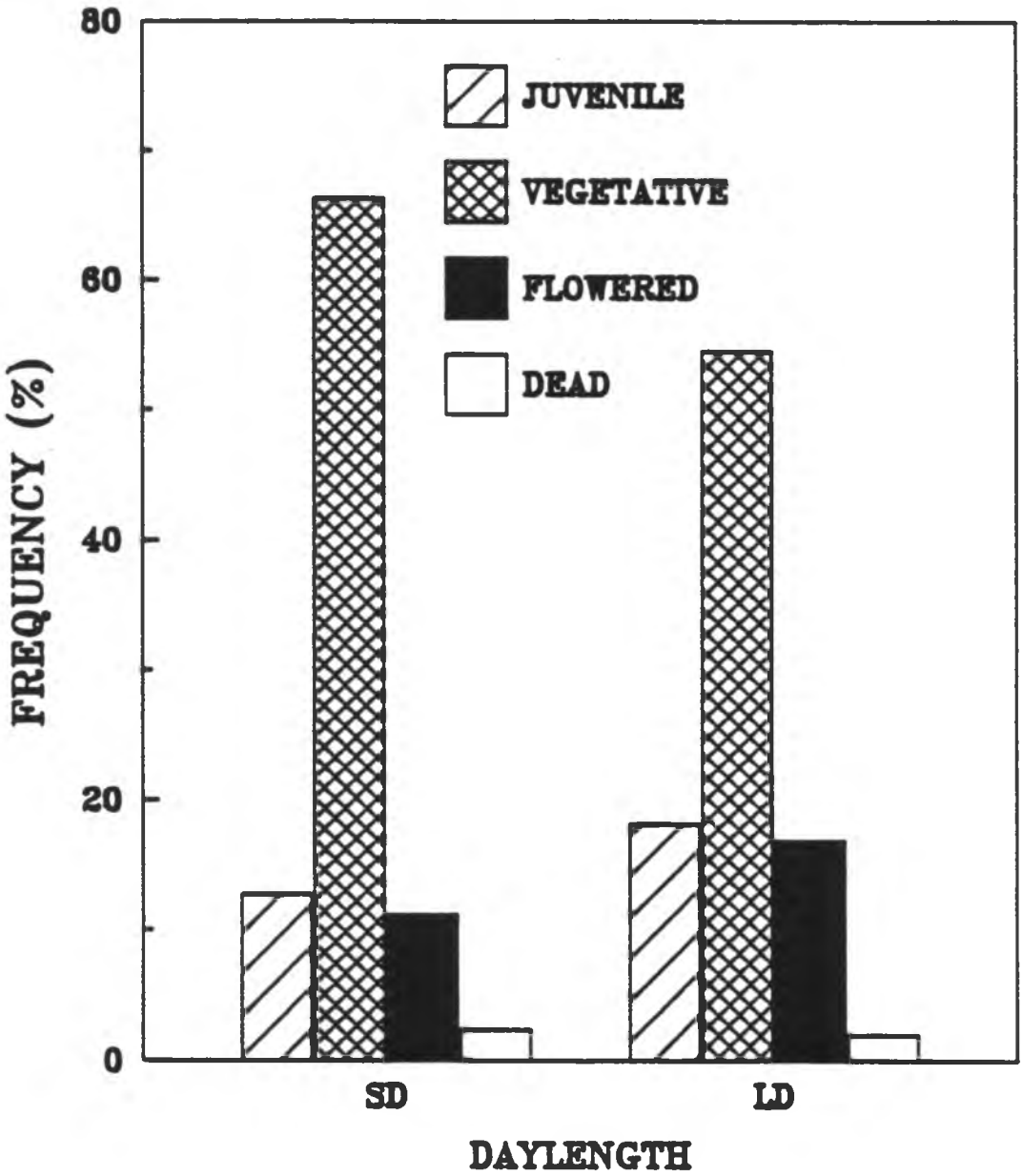


Table 13. Flowering status of H. stricta pseudostems in different generations. The distribution of pseudostems in each status were significantly different among generations with Chi-square = 274.99 (df = 12), and P = 0.0001.

		Number and (percentage) of pseudostem			
Gen.	Total	Juvenile	Vegetative	Flowered	Dead
1	79	0 (0.0) d[z]	49 (62.0) ab	17 (21.5) a	11(13.9) a
2	163	1 (0.6) d	115 (70.6) a	35 (21.5) a	2 (1.2) b
3	250	18 (7.2) c	153 (61.2) ab	48 (19.2) a	3 (1.2) b
4	193	80(41.5) b	101 (52.3) b	0 (0) b	0 (0) b
5	11	11 (100) a	0 (0) c	0 (0) b	0 (0) b

[z]Separation of percentage of pseudostems in each class (column) by Chi-Square.

Figure 11. The percentage of all H. stricta showing juvenile, vegetative, flowered and dead status in different generations averaged over 1 year in continuous SD or LD.

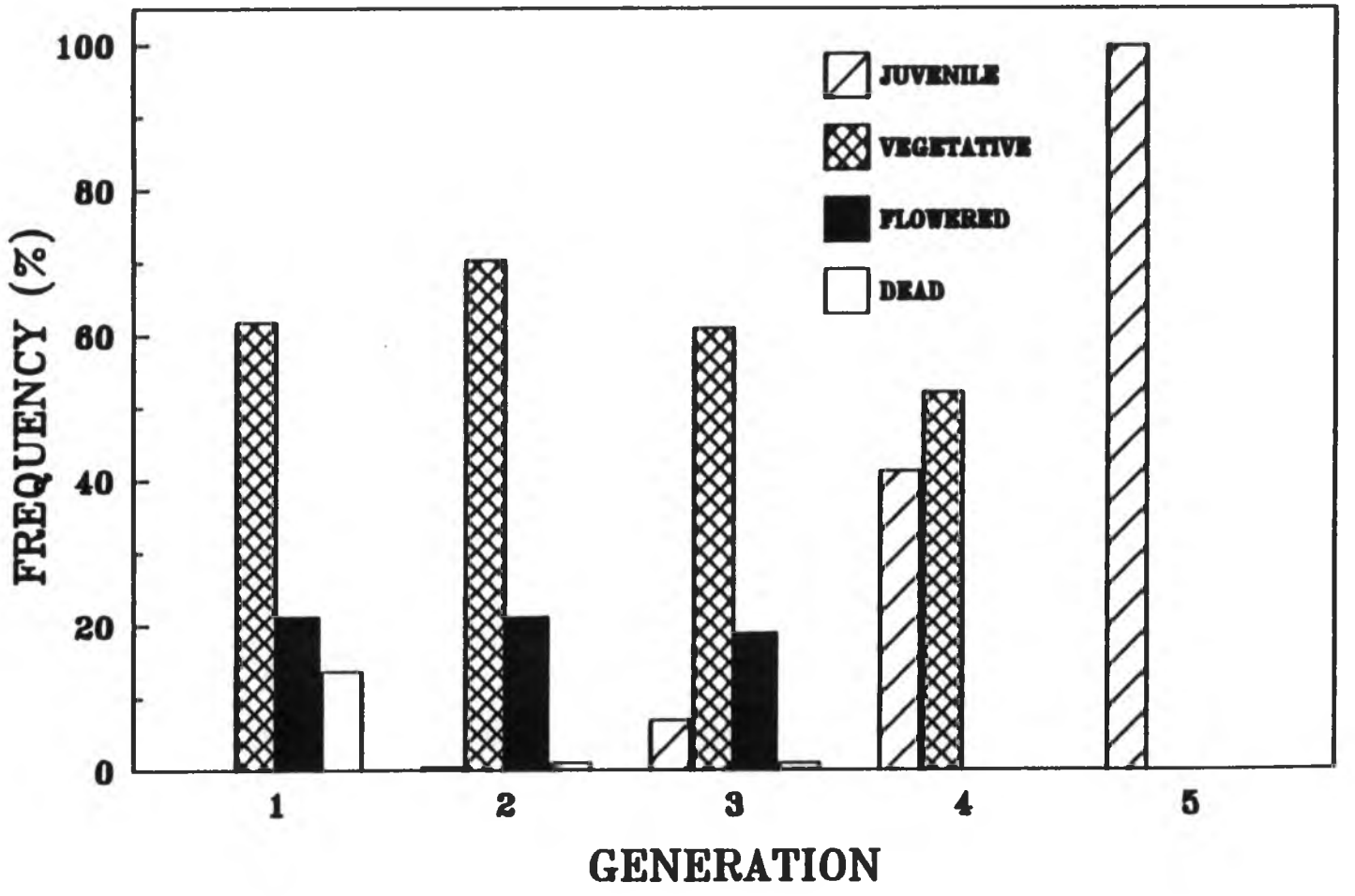
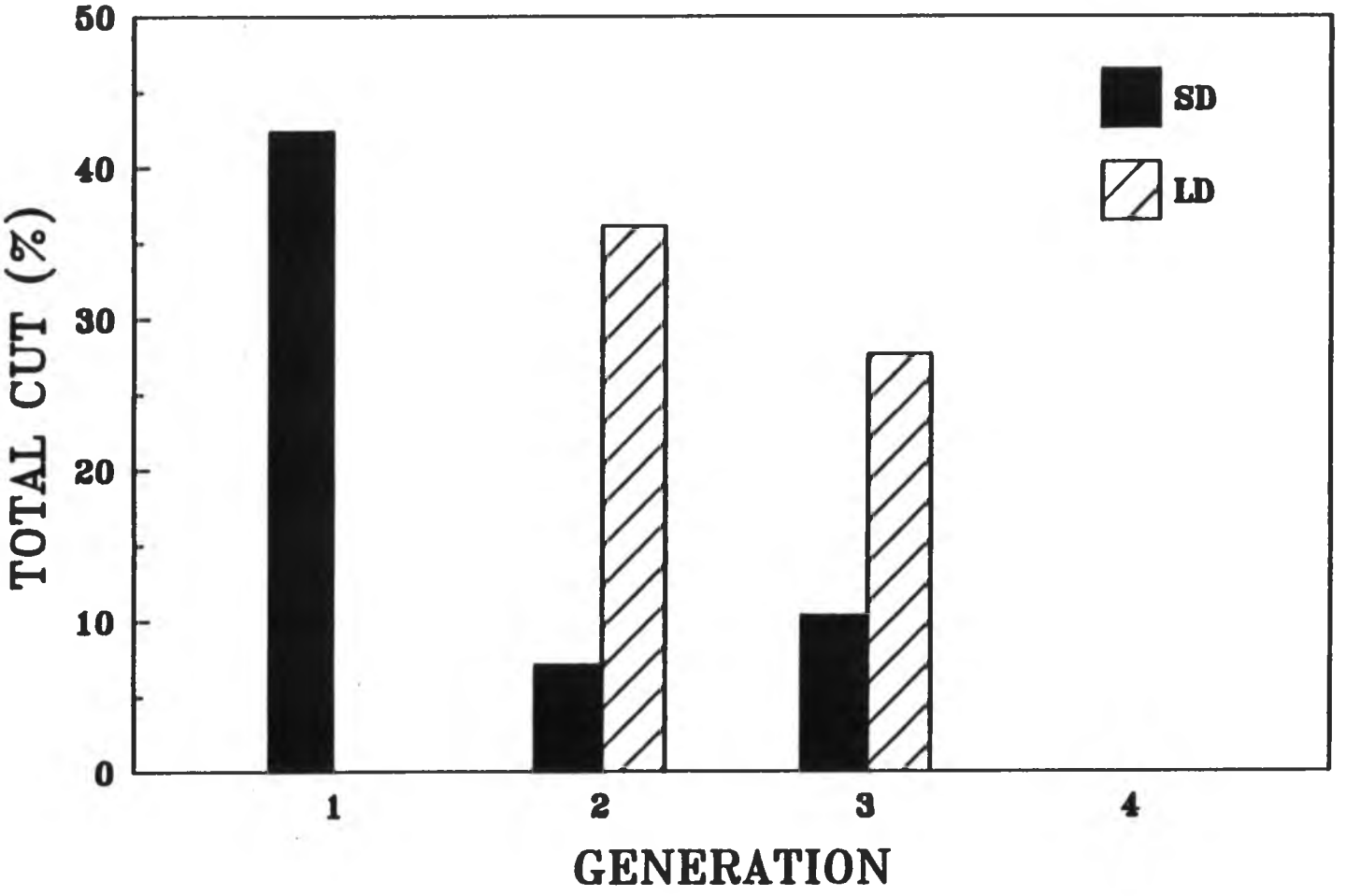


Figure 12. The flowering percentage of H. stricta pseudostems grown under SD or LD in different generations.



generation pseudostems in LD had more than 6 leaves each. However the number of leaves on each pseudostem was closer to 6 leaves with successive generations. This might be explained if first generation SD pseudostems were enhanced to flower early while LD had a strong effect in prolonging the vegetative phase or in inducing flower bud abortion in the first generation. The effect decreased with successive generations. Continuous SD might not have been favorable for inflorescence production because of less ventilation and high temperature under the black cloth shade. After 5:00 pm temperature inside the shade decreased slowly while temperature outside the shade decreased more rapidly resulting in temperatures approximately 1.5 to 2 °C higher under shade than outside for about 2 hours.

Leaves subtending an inflorescence

On pseudostems which flowered, there was no significant difference between number of leaves subtending the inflorescence in LD or SD. An average of 6.3 leaves were produced in SD and 6.2 leaves in LD (Appendix Table 40).

Inflorescence length

The length of peduncles under LD (35 cm) was significantly longer than those under SD (26 cm) at 0.0001%

level across all generations (Table 14, Appendix Table 41). The length of inflorescences from base of the first bract to the apex of the last bract of pseudostem under LD (14.6 cm) was also significantly longer than those under SD (11.6 cm) at the 1% level (Table 14, Appendix Table 42). Correspondingly the length of the inflorescences + peduncles was 49.6 cm under LD and 37.8 under SD which was also significantly different at the 0.0001 level (Table 14, Appendix Table 43). Generations had a highly significant linear effect at the 0.001 level on the length of inflorescence and inflorescence + peduncles (Appendix Table 24). The length increased with successive generations (Figure 13). Generation did not have a significant linear effect on the peduncle length but the length means increased with successive generations (Figure 13).

Pseudostem length

The length of pseudostems with 6 leaves was selected for the study because such pseudostems were considered to be matured and ready to flower. Daylength significantly affected the length of the sixth basal sheath, petiole and leaf blade (Table 15, Appendix Tables 44, 45 and 46). Generations had significant linear components with all length measurements significant at the 5% level and the

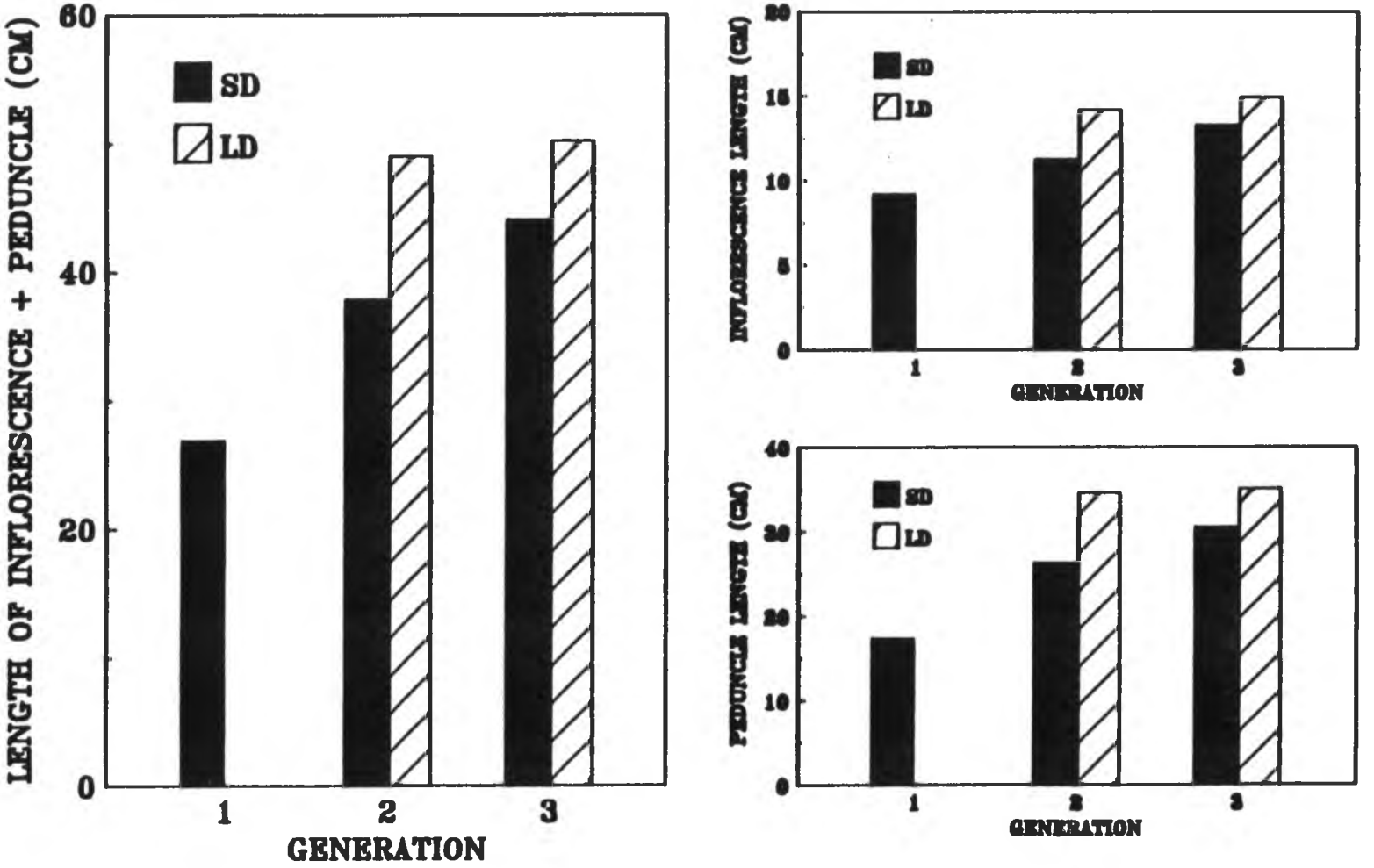
Table 14. Length of inflorescence, peduncle and inflorescence + peduncle for H. stricta under different daylengths.

Photoperiod	Peduncle	Inflorescence	Ped. + Infl.
		(cm ± SE)	
9 hr daylength	26.1 ± 3.7	11.7 ± 4.1	37.8 ± 4.1
16 hr daylength	35.0 ± 1.8	14.6 ± 2.0	49.6 ± 2.0
Significance of F value	0.0001	0.0001	0.0001

Table 15. Length of H. stricta pseudostems under different daylengths.

Photoperiod	Basal sheath+petiole	Leaf blade	Total length
		(cm ± SE)	
9 hr daylength	37.3 ± 2.9	26.4 ± 1.2	63.7 ± 3.9
16 hr daylength	57.4 ± 3.0	35.6 ± 1.2	93.0 ± 4.0
Significance of F value	0.0001	0.0001	0.0001

Figure 13. Length of inflorescence + peduncle (left), inflorescence (top right), and peduncle (bottom right) of H. stricta for generations which produced flowers.



length of pseudostems increasing with successive generations (Appendix Tables 44, 45 and 46).

The length of both inflorescence or pseudostem was longer in LD than in SD and also longer as the generation progress. New pseudostems from successive generations might have had more food reserves than those in the previous generations which resulted in longer length of both inflorescence and pseudostems. Crowding with significant stretching under low light intensity is also a possible cause of longer pseudostems in successive generations.

Conclusion

The effect of photoperiod was prominent on the inflorescence production of pseudostems in the first generation but had less or no effect in other generations. This might be due to the less LD influence due to shading of the neighboring pseudostems or less light intensity from the light bulbs with increasing time. On the other hand, less SD influence might be due to high temperature under black cloth shading which might induce flower bud abortion. Number of pseudostems in the later generations decreased in the success of daughters buds which might be caused by physiological limitations such as food reserves or mechanical limits such as limited space.

Heliconia stricta 'Dwarf Jamaican' has a potential as a flowering potted plant because of its compact and fast growing habit. As a flowering potted plant, it is important to have the shortest production cycle and many inflorescence blooming at the same time. Pseudostems in the first generation provided the shortest time to flower approximately 4 months. From a single rhizome piece approximately 1.4 pseudostem would be produced in the first generation (Figure 7, Table 11). To achieve a suitable display effect, more rhizome pieces would be planted in each pot_perhaps 2 or 3 to a 15-cm pot. Therefore many pseudostems with similar growth stages would result. This experiment showed that 42.5% of the pseudostems grown in SD in the first generation produced inflorescence while none of those in LD flowers in the first generation. However Criley and Kawabata (1986) showed that more than 90% of pseudostems with 4 leaves treated with 4 weeks of SD produced flowers approximately 13 weeks after the start of SD. It would be interesting to raise the plant in LD until most of the pseudostems in the first generation reached 4 expanded leaves, then treat with SD for 4 weeks. Thirteen weeks afterward the plants might be ready for marketing. However the production time period might be vary with season if there is a strong sensitivity to light intensity.

A simulation of the rhizome branching pattern might be developed with the basic information provided in this

experiment. However the interpretation should be done with caution because the data is from plants grown in pots under shade in the greenhouse. Field grown plants might provide different results.

CHAPTER IV

EFFECT OF DAYLENGTH ON FLOWERING OF *HELICONIA ANGUSTA*

Abstract

Plants of *Heliconia angusta* at different growth stages (1, 2, 3, 4, 5, and 6 leaves per pseudostem) were grown under 9, 10, 11, 12, and 14 hr photoperiods by employing an 9 hr natural day and low intensity incandescent lighting as a daylength extension. The differences in daylength had no significant effect on the time to flower which was approximately 17 weeks after the start of the treatment. Daylength also had no significant effect on the final proportions of flowering, vegetative or aborted pseudostems.

Introduction

Heliconia angusta or Christmas Heliconia is known for its flowering in December, around Christmastime. Criley (1985) suggested that there might be a photoresponse in this clone. However, no studies have been done on this plant. In another but faster-growing species, *H. stricta* 'Dwarf Jamaican', there was an apparent response to short daylengths (8 hr. day) if the plants had a certain number of leaves expanded at the time of treatment (Criley and

Kawabata, 1986). If flowering of H. angusta were controlled by daylength, off-season flower production might be possible. In this experiment plants of H. angusta were grown under different daylengths varying from 14 hr long daylength (LD) to 9 hr short daylength (SD) to determine whether the plant was sensitive to SD and to determine the critical daylength.

Materials and Methods

This experiment was conducted in a greenhouse at the Magoon Facility University of Hawaii. For 2 months, fifteen 25-cm tubs of established Heliconia angusta were given LD by using incandescent illumination from 6:00 pm to 10:00 pm from 60 watt lamps placed 0.8 m above the tubs. The growing medium was a mixture of soil, peat-moss and perlite.

Different photoperiod treatments were started on September 15, 1985. In each tub there were approximately 15 pseudostems which consisted of approximately 2 pseudostems with 1 leaf, 2 pseudostems with 2 leaves, 3 pseudostems with 3 leaves, 4 pseudostems with 4 leaves, 2 pseudostems with 5 leaves, and 1 pseudostem with 6 leaves, for a 15-tub total of 225 pseudostems. Each pseudostem was tagged to identify the initial leaf number. The experiment was conducted as a completely randomized design with each pseudostem as an experimental unit.

Black cloth partitions were used to create 5 chambers to which were assigned 3 tubs each for daylength treatments. An automatic black cloth shading system drawn from 5:00 pm to 8:00 am created a 15 hr dark period. Supplemental light from a single 60-W incandescent lamp in each chamber extended the 9 hours of natural daylight by 0, 1, 2, 3, and 5 hours, to provide photoperiods of 9, 10 11, 12, and 14 hours and there were 41, 37, 39, 37 and 45 pseudostems in each treatment respectively. The experiment was terminated on March 9, 1986, 23 weeks after the start of treatment. Plants were drip-irrigated with a nutrient solution, 200N-0P-200K (ppm), at the rate of 2000 ml per tub per day. The maximum air temperature during July 15, 1985 to March 9, 1986, ranged from 29.5° to 38°C with a mean of 35.9 °C. Night air temperature ranged from 19.5° to 23.5°C with a mean 22.3°C for the same period. The maximum illuminance in the greenhouse was 71 klx.

When inflorescences emerged, data were collected at one week intervals including week of anthesis (of first flower in lowest bract), length of inflorescence and peduncle combined, number of leaves subtending inflorescence and time for new leaf expansion. For pseudostems that did not show an inflorescence, a determination of status (vegetative or aborted) was made by dissecting the stem at the conclusion of the experiment.

The leaf numbers at the start of the treatment period differed among pseudostems within daylength treatments, and the number of pseudostems in each treatment differed. Therefore an analysis of covariance was used to increase precision by removing from the experimental error variation in the dependent variables (weeks to anthesis, length of inflorescence, etc.) associated with the covariate (initial leaf number) and to adjust the treatment means of dependent variables for differences existing in the covariate (Bender et el., 1982). Separation of adjusted treatment means was done with Duncan's multiple range test.

To analyze quatitative data such as number of flowering, vegetative or aborted pseudostems, Chi-Square tests for independence were used. The null hypothesis in this was that the differences existing among the proportions of observations in each class (flowered, vegetative or aborted) were independent of photoperiod treatments or initial leaf number differences. If the null hypothesis was rejected, percentage of pseudostems in each class were performed Chi-Square test for a fixed ratio hypothesis. The test was done on different pairs of pseudostem percentage within each class. The null hypothesis was that percentage of pseudostems between two different photoperiods or different initial leaf numbers were not significantly different. This test enabled the separation of percentage of pseudostem in different photoperiods or initial leaf

numbers within a class. The null hypothesis was rejected when the significance probability was less than 0.05 level.

Results and Discussion

Time to flower

There were 31 inflorescences produced out of a final population of 199 pseudostems (26 pseudostems died), and their distribution by daylength treatment is shown in Table 16. Because of the small number of inflorescences relative to the population of pseudostems, caution is necessary in interpreting results and trends.

There were no differences at the 5% level of significance among treatment means for time to first anthesis in different photoperiods (Appendix Table 47). The time to flower averaged 16.7 weeks after the treatment began (Table 16). However there was significant linear regression of time to flower on the initial leaf number (covariate) at the 5% level (Appendix Table 47). Pseudostems with more leaves at the start of treatment tended to require less time from the beginning of treatment to first anthesis than those with fewer initial leaves (Table 17). This might be an indication that a certain number of leaves have to be produced prior to flowering. Pseudostems with 1-3 initial

Table 16. Inflorescence production and number of weeks to first anthesis from begining of treatment for H. angusta under different daylengths.

Photoperiod (hr)	Inflor. Nos.	Weeks to anthesis (wks ± SE)
9	5	18.3 ± 2.7
10	5	14.4 ± 2.7
11	5	16.5 ± 2.7
12	6	16.8 ± 2.4
14	10	17.1 ± 1.9
Significance of F value		NS[z]

Table 17. Inflorescence production and number of week to first anthesis from begining of treatment of H. angusta with different initial leaf numbers, averaged over all photoperiod treatments.

Initial leaf No.	Total No. of Pseudostem	Inflor. No.	Weeks to anthesis (wks ± SE)
1	24	4	18.0 ± 3.0
2	34	4	20.0 ± 3.0
3	33	8	18.6 ± 2.1
4	63	14	14.5 ± 1.6
5	33	1	14.0 ± 5.9
6	12	0	--

leaves took longer to flower than those with 4 and 5 initial leaves.

Pseudostem status

Effects of photoperiods and initial leaf numbers on the distribution of pseudostem final status are shown in Figure 15 and Table 18, 19.

The proportions of flowering, vegetative and aborted pseudostems among different photoperiods showed no significant differences (Table 18). In most photoperiod treatments the percentage of aborted pseudostems was higher than those of vegetative and flowered pseudostems respectively (Figure 14).

The proportions of flowering, vegetative and aborted pseudostems among different initial leaf numbers showed significant differences at 10% and 1% level respectively (Table 19). Pseudostems with 3 and 4 initial leaf number tended to yield more inflorescences than those with 1, 2, 5 and 6, respectively. This might suggested that pseudostems with 3 or 4 expanded leaves were more sensitive to a floral stimulus than those with fewer expanded leaves. The percentage of vegetative pseudostems was high for pseudostems with 1 initial leaf and decreased as initial leaf number increased. As the initial leaf number increased the number of aborted pseudostem also increased which

Table 18. Flowering status of H. angusta pseudostems under different daylengths. The distribution of pseudostems in each status were not significantly differences among treatments with Chi-square = 4.858 (df = 8), and P = 0.772.

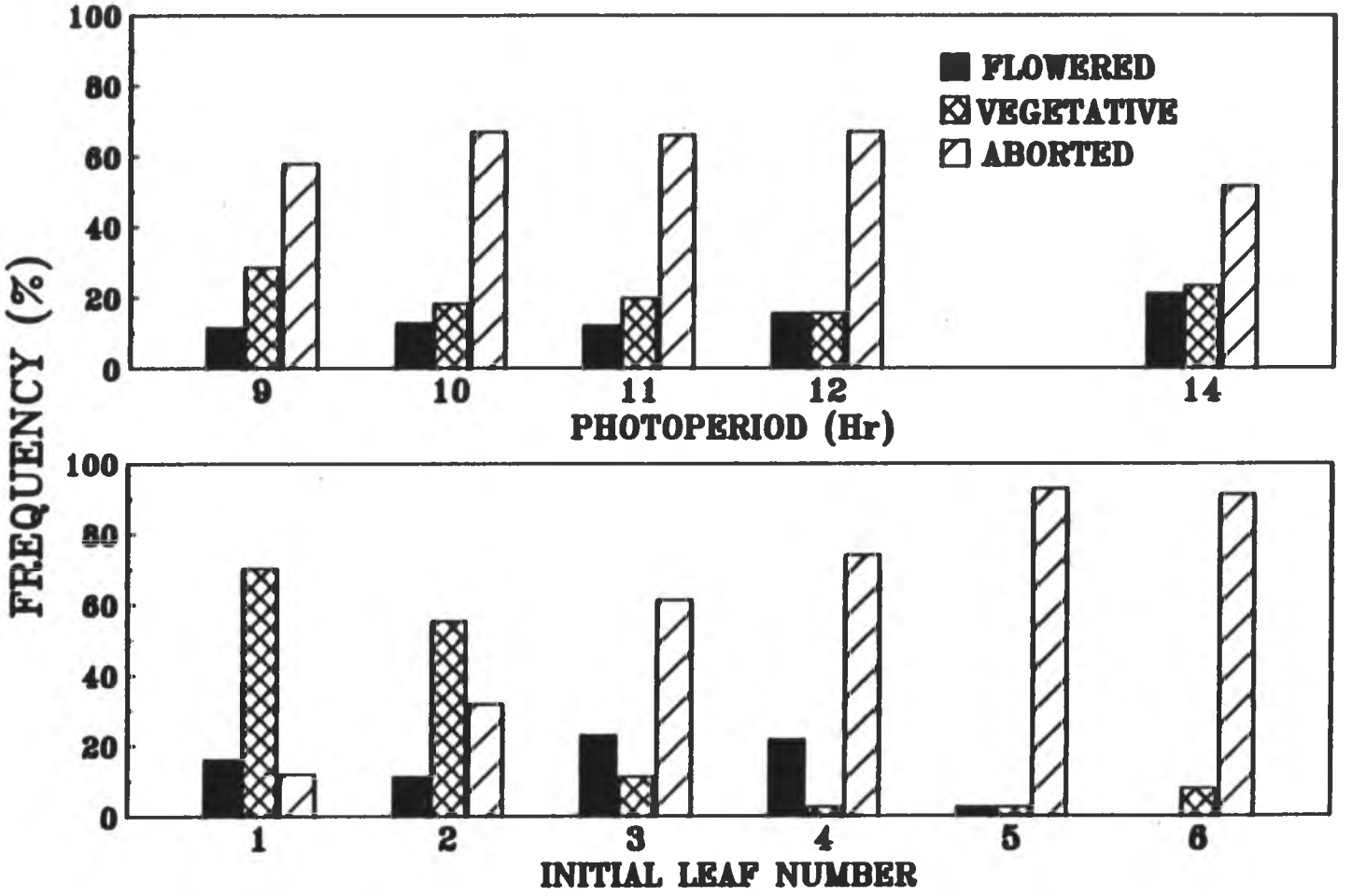
Photoperiods (hr)	Number and (percentage) of pseudostem			
	Total	Flowered	Vegetative	Aborted
9	41 (100)	5 (12.2)	12 (29.2)	24 (58.5)
10	37 (100)	5 (13.5)	7 (18.9)	25 (67.5)
11	39 (100)	5 (12.8)	8 (20.5)	26 (66.6)
12	37 (100)	6 (16.2)	6 (16.2)	25 (67.5)
14	45 (100)	10 (22.2)	11 (24.4)	24 (53.3)

Table 19. Flowering status of H. angusta pseudostems with different initial leaf numbers. The distribution of pseudostem in each status were significantly different among different initial leaf numbers with Chi-square = 93.340 (df = 10), and P = 0.0001.

Ini.lf.No.	Number and (percentage) of pseudostem			
	Total	Flowered	Vegetative	Aborted
1	24	4 (16.6) ab[z]	17 (70.8) a	3 (12.5) c
2	34	4 (11.7) ab	19 (55.8) a	11 (32.3) c
3	33	8 (24.2) a	4 (12.1) b	21 (63.6) b
4	63	14 (22.2) a	2 (3.1) b	47 (74.6) b
5	33	1 (3.0) b	1 (3.0) b	31 (93.9) a
6	12	0 (0.0) b	1 (8.3) b	11 (91.6) ab

[z]Separation of percentage of pseudostems in each class (column) by Chi-Square.

Figure 14. Effect of photoperiods and initial leaf number on the reproductive/ vegetative status of H. angusta after 23 weeks of treatment. (100% = each photoperiod or initial leaf number unit)



resulted in the lowering of the percentage of vegetative and flowered pseudostems (Figure 14). This might be due to the following reasons:

a) The pretreatment of pseudostems for 2 months with LD might cause abortion especially to pseudostem with 5 or 6 leaves at the start of SD. At this stage of growth, pseudostems might be sensitive to an abortion stimulus or inhibitor induced by LD condition.

b) Temperature under the black cloth shading system used for daylength treatments might not be favorable to plant growth. Growing plants continuously in this condition might have caused plant stress which finally resulted in abortion.

Number of leaves subtending the inflorescence

Effects of photoperiods and initial leaf numbers on the number of leaves subtending the inflorescence are shown in Tables 20 and 21.

There were significant differences among number of leaves subtending inflorescence in different photoperiods at the 5% level (Appendix Table 48). The number of subtending leaves under the 11 hour photoperiod (5.6 leaves) was significantly higher than the means for those in 9, 10, 12,

Table 20. Final number of leaves subtending inflorescence and inflorescence length of H. angusta under different daylengths.

Photoperiods (hr)	No. of subtending leaves	Inflorescence + peduncle length (cm)
9	4.8 b[z]	51.5 a
10	4.5 b	50.0 a
11	5.6 a	44.3 b
12	4.5 b	37.2 b
14	4.9 b	43.7 ab
Significance of F value	0.034	0.056

[z]Mean separation in columns by Duncan's multiple range test.

Table 21. Final number of leaves subtending inflorescence and inflorescence length of H. angusta with different initial leaf numbers.

Initial leaf No.	No. of subtending leaves (± SE)	No. of new leaves	Inflorescence + peduncle length (cm ± SE)
1	4.2 ± 0.6	3.2	52.0 ± 15.1
2	4.5 ± 0.6	2.5	44.3 ± 8.7
3	5.1 ± 0.4	2.1	45.0 ± 6.7
4	4.9 ± 0.3	0.9	45.2 ± 4.2
5	6.0 ± 1.1	1.0	35.0 ± 15.1

and 14 hour photoperiod (5 leaves) at the 5% level (Table 20).

The linear regression of the number of leaves subtending the inflorescence on initial leaf number (covariate) was also significant at the 1% level (Appendix Table 48). The number of subtending leaves increased as the number of initial leaves increased (Table 21). However fewer new leaves were added to shoots with a larger initial leaf number than to those with a low starting number. This indicates that the pseudostems have to reach at least 4 to 5 leaves prior to flowering. This suggests an immediate and early effect of photoperiod on flower bud initiation on pseudostems with more leaves at the start of treatment.

Inflorescence and peduncle length

Effects of photoperiod and initial leaf numbers on combined inflorescence and peduncle length are shown in Tables 20, 21 and Figure 15.

There were no differences among the length of inflorescence + peduncle in different photoperiods at the 5% level (Appendix Table 49). However lengths of inflorescences in 9 and 10 hour photoperiods were significantly greater than the length of those in the 12 hour photoperiod, while the lengths of those in 11 and 14 photoperiods were not significantly different from the

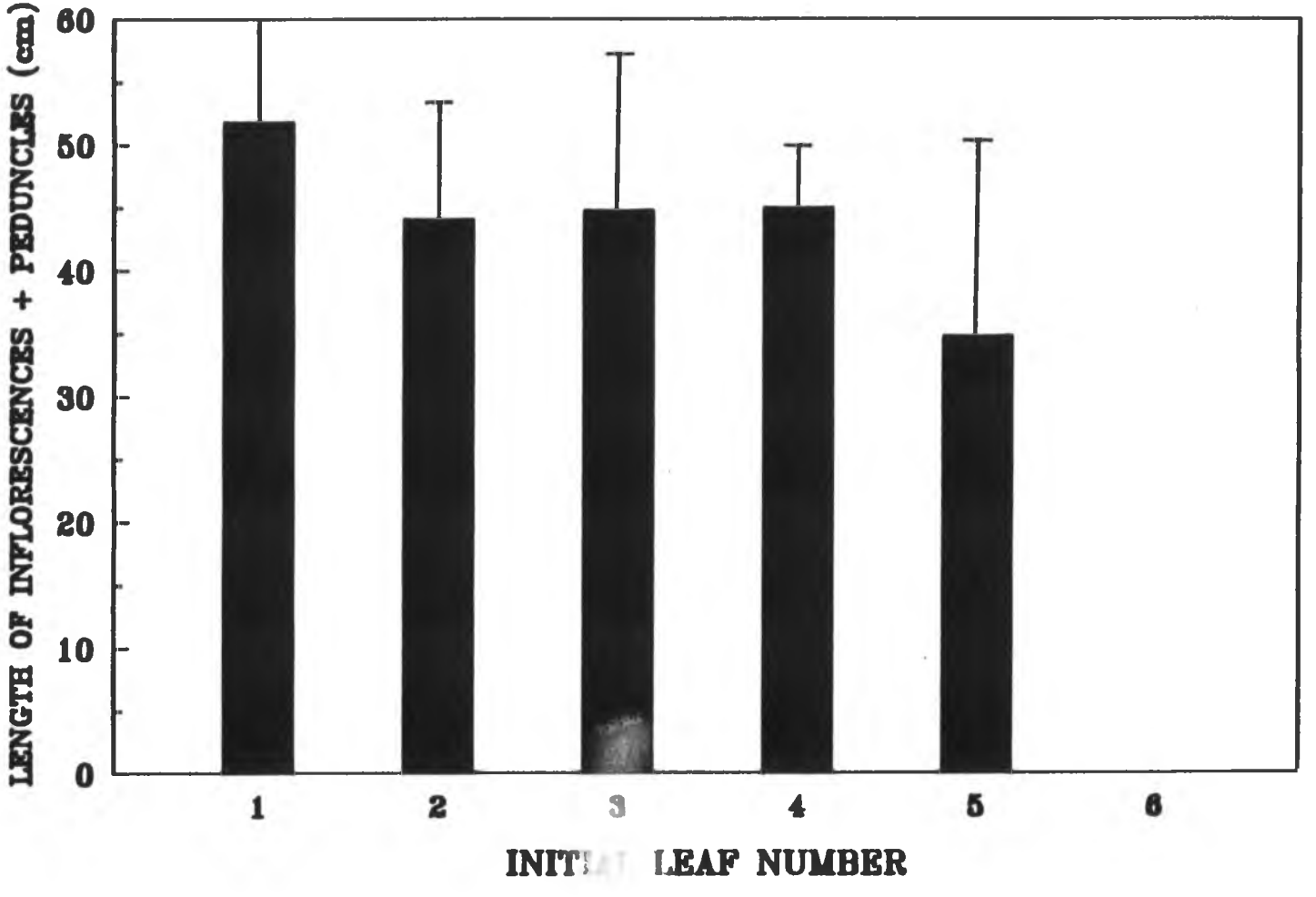
others at the 5% level (Table 20). The trend for inflorescence + peduncle length to be shorter with longer photoperiods were in contrast to the previous studies (Chapter 3) on H. stricta 'Dwarf Jamaican' for which inflorescence length in LD was longer than for those in SD (8 hour day).

The linear regression of inflorescence length on initial leaf number (covariate) was also not significant at the 5% level (Figure 15, Table 21, Appendix Table 49). However there was a inverse relationship of length to initial leaf number. Since pseudostems with more initial leaves flowered faster than those with fewer initial leaf number, there was probably less stem to elongate. Also, with more time to grow and a (potentially) increasing shade effect from new leaves of neighboring plants and low winter light, stretching could be the explanation for longer inflorescence + peduncle in pseudostems with more internodes left to elongate; that is, those with few leaves expanded at the start of treatment.

Time for new leaf expansion

The time period for pseudostems to produce one expanded leaf to another one varied with initial leaf number. Pseudostems with 1 and 2 initial leaf numbers were more consistent in the period (4-5 weeks) than others with more

Figure 15. Effect of initial leaf numbers on length of inflorescences and peduncle combined of H. angusta, average over photoperiod treatments, 23 weeks after the start of treatment.

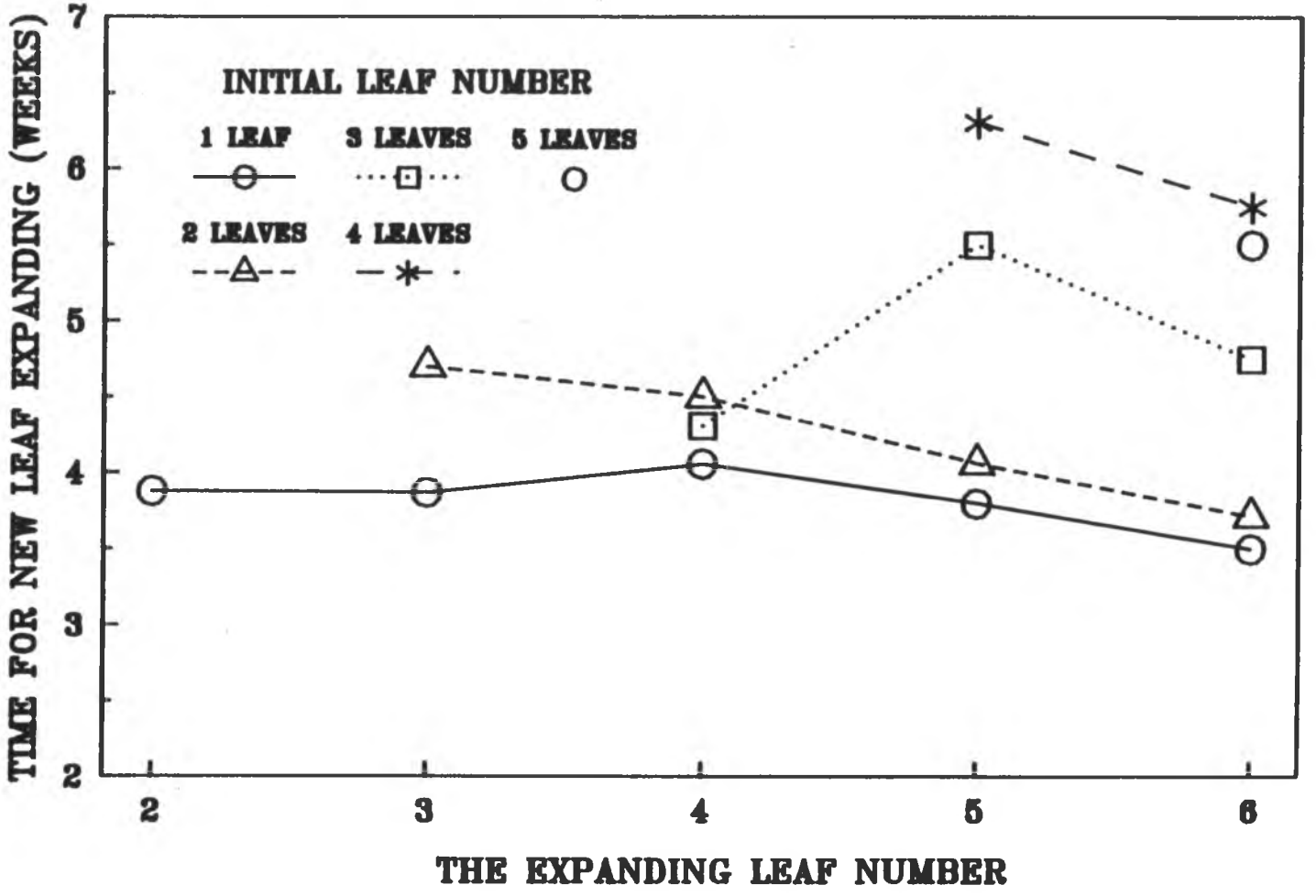


leaves (Figure 16). Most of the pseudostems with 5 and 6 initial leaves did not produce any more leaves. This indicated that the pseudostems with more leaves at the start of treatment were not growing as actively as those with fewer leaf number.

Under the conditions of this experiment, the frequency of leaf production can be 4-6 weeks (Figure 16) which suggests that a period of 20 to 30 weeks could be spent in foliage growth and development. Since leaf number is almost constant in terms of leaves subtending the inflorescence (5-6), the apical meristem may not be responsive to environment at all or it may respond only after 5 or 6 leaves have been produced. Since pseudostem with 3 or 4 intial leaves had higher flowering percentage thon those with fewer or more leave number (Table 18). Other studies have suggested that a 3-4 visible stage is critical (Criley and Kawabata, 1986), it may be well to examine pseudostem of this stage more critically.

Since there were no difference in this experiment among photoperiods in number of weeks to first anthesis and in number of inflorescences, the critical daylength for inducing flowering in H. angusta could be determined, if indeed, daylength does influence flowering. The low yield was probably due to variation among the experimental unit as:

Figure 16. Time period for pseudostems of H. angusta to produce one expanded leaf as a function of initial leaf number, average for the next leaf to appear over all status.



a) The growing medium included soil and may have had poor drainage and aeration. Nematode damage was also detected. Both effects could have had negative effects on root and rhizome growth.

b) Many pseudostems at the start of the daylength treatments were not actively growing and the apical meristem might have aborted already due to the LD pretreatment or poor condition of the roots.

c) During the treatment period pseudostems might have received unsuitable growing condition such as low light intensity, and high temperature which also reduce photosynthate. If photosynthate is limiting, development might be arrested until the factor no longer limits. If photosynthate is limiting for a long period of time, the apical meristem might abort.

To improve the methodology for the next experiment on this plant the above factors should be considered. Soilless media might be a good solution for aeration, drainage and nematode problems. Select only actively growing plants still able to produce new leaves. Light intensity should be controlled to have the same level throughout the experiment. Ventilation in the black cloth shading system should also be considered.

CHAPTER V

COMPARATIVE ANATOMY OF APICAL MERISTEM OF *HELICONIA STRICTA* IN DIFFERENT DAYLENGTH

Abstract

Apical meristems from plants of *Heliconia stricta* 'Dwarf Jamaican' growing under short (9 hours photoperiod) and those under long (approximately 16 hour photoperiod) daylengths at different growth stages (1-6 expanded leaves) were observed as 20 micrometer thick sections. The inflorescence structure was distinguishable in plants under short daylength when pseudostems reached 3 or more expanded leaves while inflorescence structures could not be identified in pseudostems growing under the long daylength.

Introduction

Criley and Kawabata (1986) suggested that *Heliconia stricta* 'Dwarf Jamaican' might respond as a facultative short daylength plant. Their studies showed that plants grown under continuous 9-hr short daylength (SD), or given SD for 4 to 6 weeks flowered while plants given continuous long daylength (LD, approximately 18-hr daylength) or only 1 to 3 weeks of SD did not flower. Another study of Criley and Kawabata (1986) showed that if the plants had fewer than

3 leaves at the time of 4 week SD treatment (8-hr daylength), inflorescence production was lower than those of pseudostems with 4 or more visible leaves. The pseudostems with 3 or fewer initial leaves had higher percentage of abortion than did pseudostems with 4 or more initial leaves. Their results lead to the question of whether the apical meristems of the plant grown under LD were still vegetative and susceptible to a floral stimulus or whether they were aborted by the influence of LD. Another question was why pseudostems with fewer than 3 leaves when treated with SD did not respond well while pseudostems with 4 or more leaves developed inflorescences readily. It was suggested that the apical meristem of pseudostems with fewer than 4 visible leaves were still vegetative and were not susceptible to a floral stimulus (Criley and Kawabata, 1986).

This experiment was established to determine the correlation between total final leaf number and the number of visible expanded leaves under SD or LD at the time of development of the apical meristem to a reproductive condition.

Materials and Methods

Ten rhizome pieces of H. stricta 'Dwarf Jamaican' were potted singly in 15-cm pots on June 20, 1985, in a greenhouse at the University of Hawaii Magoon facility. The

potting medium was a mixture of peat and perlite at 1:1 ratio (V/V) and amended with dolomite, Micromax and treble superphosphate at the rate of 6.0, 1.0 and 0.6 kg per cubic meter, respectively. One half of the pots were given 9 hours photoperiod (SD) using automatic black cloth shading system from 5:00 pm to 8:00 am. The other half of the pots were given LD by using incandescent illumination from 6:00 pm to 10:00 pm (LD, approximately 16-hr daylengths) from 60-W lamp placed 1.3 m above the pots. Plants were drip irrigated with nutrient solution , 200N-0P-500K (ppm), at the rate of 1000 ml per pot per day.

After 3 months, September 14, 1985 to September 25,1985, tissues in the meristematic region were selected from plants at different growth stages using expanded leaf number (at the time the last leaf had just expanded) as the index (1 to 6 leaves). Five tissue samples were selected for each growth stage.

During the SD and LD treatment: the maximum air temperature ranged from 34.9°C to 38.5°C with a mean of 37.7°C, the night air temperature ranged from 23.0°C to 24.1°C with a mean of 23.6°C and the maximum illuminance in the greenhouse was 71 klx.

Tissues to be examined were fixed in FAA solution (formalin-aceto-alcohol) and dehydrated in a graded series of ethyl alcohol-tertiary butyl alcohol (TBA) solutions.

Infiltration with Parowax and embedding in Paraplast followed a standard paraffin embedding technique (Johansen, 1940). Sections were made on a rotary microtome at 20 micrometer thickness. Tissue were stained with 0.05% toluidine blue 0 (Sakai, 1973). From each growth stage, one sample which showed the most advanced meristem development was selected. Photomicrographs were prepared to illustrated this portion of the study. The vegetative apical meristem and reproductive apical meristem were compared. The measurements were done on width of the meristems which was the distance between the outer of the basal part of primordium, and height of the meristem which was the distance from the basal part of the primordium to the tip of the apical meristem. The measurement data were analyzed by regression.

Results

The total leaf number at the conclusion of this experiment consisted of expanded leaves and leaves enclosed in the pseudostem. In SD, pseudostems with 2 to 6 expanded leaves at the start of treatment finished with 6 total leaves while the ones with 1 expanded leaf at the start had 4 total leaves at the conclusion of the experiments (Plate I). At the stage of 3 expanded leaves the first and the second cincinnal bracts were distinguishable and pseudostem

elongation was observed. At the stage of 4 expanded leaves flower primordia were conspicuous. In LD, the final leaf count for pseudostems with 1 expanded leaf was 5 leaves, while pseudostems with 2, 3 and 4 visible, expanded leaves had 6 leaves (Plate II). The total final leaf number for LD pseudostems with 5 and 6 expanded leaves was 8 leaves. Neither inflorescence elongation nor inflorescence structure was observed in LD pseudostems. However, no sign of abortion in the meristematic region was observed either.

There were no significant differences in the widths of apical meristems of plants grown in SD or in LD, at the 5% level (Table 22, Appendix Table 50). The number of visible leaves had a significant linear effect on the width of apical meristem at 5% level as the apical region became broader with the increase in number of visible leaves. The height of apical meristems was significantly different between plants grown in SD and LD (Table 22, Appendix Table 51). The number of visible leaves had a significant linear effect on the height of apical meristem of plants grown in both SD and LD but the slopes of the two regression lines were different (Figure 17, Appendix Table 51). The rate of increase in apical meristem height per visible leaf number of plant grown in SD was higher than the rate of plants grown in LD.

Table 22. Apical meristem height and width of H. stricta'Dwarf Jamaican' plants with different leaf numbers and two photoperiods (SD and LD).

Leaf No.	Height (micrometer)		Width (micrometer)	
	SD	LD	SD	LD
1	88.5	118.5	325.9	355.6
2	118.5	148.2	266.7	711.1
3	977.8	177.8	1037.0	681.5
4	1037.0	266.7	1125.9	977.8
5	1274.1	237.0	859.3	651.8
6	2222.2	267.7	1007.4	740.7

Figure 17. Height of apical meristem of H. stricta pseudostems with different visible, expanded leaf number and grown under SD or LD.

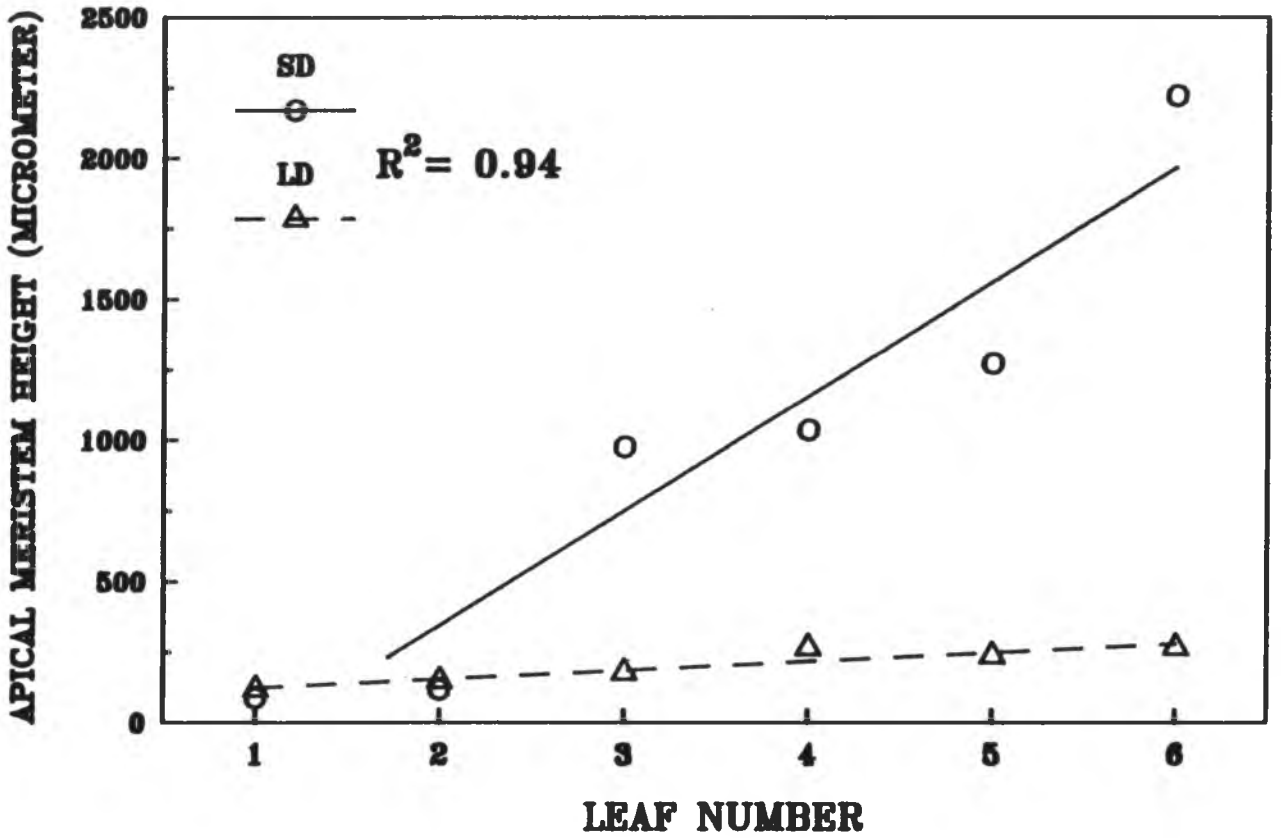


PLATE I

Apical longitudinal section of H. stricta 'Dwarf Jamaican' pseudostems grown under SD (9-hr daylength) with different expanded leaf (not visible in the photomicrograph) and total leaf numbers (magnification: 28X).

A. Pseudostem with 1 visible, expanded leaf and 4 total leaves produced.

B. Pseudostem with 2 visible, expanded leaves and 6 total leaves produced.

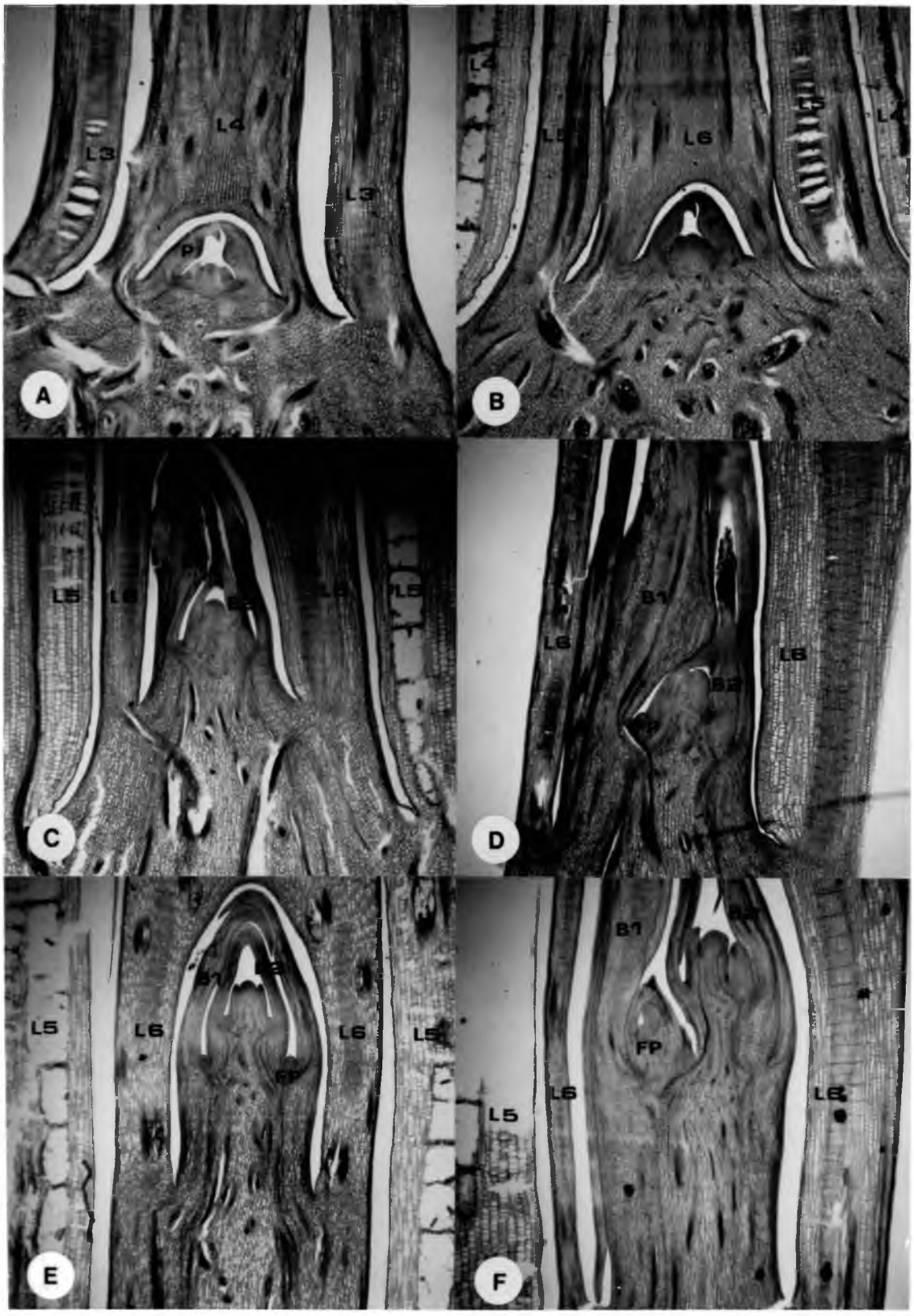
C. Pseudostem with 3 visible, expanded leaves and 6 total leaves produced.

D. Pseudostem with 4 visible, expanded leaves and 6 total leaves produced, showing flower bud primordia at the base of cincinnal bracts.

E. Pseudostem with 5 visible, expanded leaves and 6 total leaves produced.

F. Pseudostem with 6 visible, expanded leaves and 6 total leaves produced.

L = leaf number, B = cincinnal bract,
P = unidentified primordium, FP = flower bud primordium


L3
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L3
P
A
L4
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B
L5
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L5
C
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B1
B2
L6
D
L5
L6
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B2
L6
L5
E
L5
L6
B1
B2
FP
L6
L5
F
B1
B2
FP
L6
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L6

PLATE II

Apical longitudinal section of H. stricta 'Dwarf Jamaican' pseudostems grown in LD (approximately 16-hr daylength) with different expanded leaf (not visible in the photomicrograph) and total leaf numbers (magnification: 28X).

A. Pseudostem with 1 visible, expanded leaf and 5 total leaves produced.

B. Pseudostem with 2 visible, expanded leaves and 6 total leaves produced.

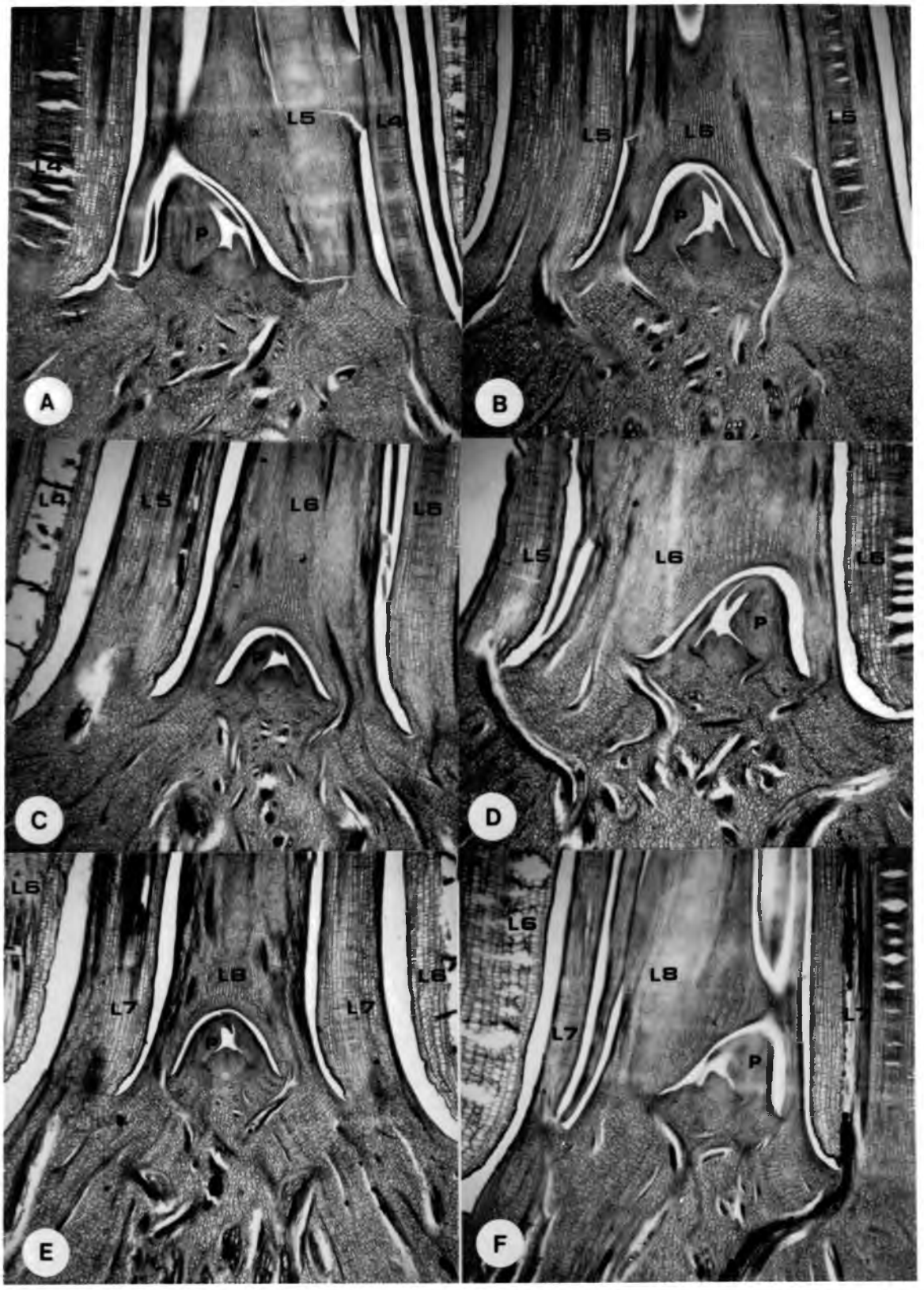
C. Pseudostem with 3 visible, expanded leaves and 6 total leaves produced.

D. Pseudostem with 4 visible, expanded leaves and 6 total leaves produced.

E. Pseudostem with 5 visible, expanded leaves and 8 total leaves produced.

F. Pseudostem with 6 visible, expanded leaves and 8 total leaves produced.

L = leaf number, B = cincinnal bract,
P = unidentified primordium, FP = flower bud primordium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F

Discussion

From these results the onset of inflorescence development of plants in LD could not be determined. The apical meristem of plants in LD may remain vegetative under the influence of LD, or inflorescence initiation might occur after more than 6 expanded leaves were produced. The apical meristem might abort after a certain number of leaves were produced if an inducing stimulus did not occur. However abortion of the apical meristem was not found in this study. In SD, initiation of the inflorescence may happen sometime between when pseudostems had 2 or 3 expanded leaves because: at the 2 expanded leaf stage the total number of leaves had just reached 6 leaves, the inflorescence structure were conspicuous at the 3 expanded leaf stage, the apical meristems of pseudostems with 1 leaf were still producing vegetative leaves, and the apical meristem of pseudostems with 4 or more visible leaves were developing the inflorescences.

Apical meristems of pseudostems with 2 or 3 expanded leaves or more (up to 5 leaves) were capable of differentiating into inflorescences if exposed to SD. One interpretation of previous results (Criley and Kawabata, 1986) could be that the pseudostems with 1 leaf did not yield many inflorescences because most of the apical meristems were in the vegetative phase and not capable of

responding to a floral stimulus. However pseudostems with 2 or 3 expanded leaves did not yield many inflorescences when they should already have had 6 total leaves. There might not have been enough time, in the Criley and Kawabata (1986) studies, after leaf number reached 2 to 3 for the SD stimulus to have its effect. The pseudostems in LD also did not yield many inflorescences might be due to the apical meristems were still in the vegetative phase and were not susceptible to a floral stimulus.

Since the results from this experiment were from a small number of observations, the experiment was just a preliminary one. For more accurate interpretation, a further study on differentiation of the apical meristem in SD should be done from the beginning of the shoot emergence until pseudostems have about 3 leaves by using expanded leaf number together with time period as indexes, and the number of observation should also be increased.

CHAPTER VI

CONCLUSION

Growth and flowering of 2 species of Heliconia (H. stricta Huber 'Dwarf Jamaican' and H. angusta Vell.) were studied to progress towards a goal of controlled flower production and cultural management.

H. stricta rhizome branching pattern seems to be hexagonal system with an average of 4 generation produced over a year. The success and failure of sympodial units, and their length were examined to provide a basis for further predicting of production yield and coverage area of the plant in a particular period of time.

Environmental factors had significant effects on flowering of H. stricta. Short daylength (SD, 9 hr photoperiod) hastened flowering of the plants while long daylength (LD, approximately 16 hr photoperiod) delayed or inhibited flowering. Pseudostems with 3 expanded leaves developed inflorescences under SD while none of pseudostems with 1 to 6 expanded leaves developed an inflorescence under LD. The results confirmed the works of Criley and Kawabata (1986) which suggested that H. stricta 'Dwarf Jamaican' might be a facultative shortday plant. Night temperature (15°, 20°, and 25°C) also had significant effect on flowering of H. stricta at 1 to 3 expanded leaves stages. Pseudostems with 3 expanded leaves grown under 15°C and 8 hr

daylength for 4 weeks showed the highest flowering percentage.

The study of photoperiod influences on flowering of H. angusta showed that pseudostems with 3 or 4 expanded leaves might be sensitive to a floral stimulus. However the critical daylength for inducing flowering in H. angusta could not be determined.

The above results provide some further information on the influence of environment on growth and flowering of Heliconia spp. However more information still need to be studies for better understanding of the growth and flowering of the plants. From these and the Criley and Kawabata (1986) studies, the following should be considered for next experiments on H. spp.

a) Time to flower for H. stricta pseudostems with 1-3 expanded leaf at the time of SD treatment was longer than pseudostems with 4 or more leaves.

b) The influence of SD and LD decreased with successive generation for H. stricta.

c) H. angusta pseudostems at 3-4 expanded leaves stage should be examined more critically since it seem to response well to a floral stimulus.

d) High night air temperature of the plants under shading might not be favorable to flower development.

APPENDIX

Table 23. ANOCOVA Effect of night temperature and initial leaf number on number of days to first anthesis from the start of treatment of *H. stricta*.

Source	df	SS	MS	F[z]
Temperature	2	83.83	41.91	0.21[NS]
Initial leaf (Regr.)	1	786.75	786.75	3.89[NS]
Error	61	12338.30	202.27	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 10.58

Table 24. ANOCOVA Effect of night temperature and initial leaf number on number of leaves subtending inflorescence of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	1.36	0.68	2.36[NS]
Initial leaf (Regr.)	1	1.57	1.57	5.44[*]
Error	61	17.61	0.29	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 10.0

Table 25. ANOCOVA Effect of night temperature and initial leaf number on length of peduncle of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	61.69	30.84	5.41[**]
Initial leaf (Regr.)	1	6.70	6.70	1.18[NS]
Error	57	325.00	5.70	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 13.86

Table 26. ANOCOVA Effect of night temperature and initial leaf number on length of inflorescence of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	44.10	22.05	7.21**
Initial leaf (Regr.)	1	0.49	0.49	0.16NS
Error	57	174.31	3.06	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 13.9

Table 27. ANOCOVA Effect of night temperature and initial leaf number on length of inflorescence and peduncle combined of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	216.82	108.41	11.93**
Initial leaf (Regr.)	1	12.65	12.65	1.39NS
Error	54	490.67	9.08	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 10.15

Table 28. ANOCOVA Effect of night temperature and initial leaf number on length of the first cincinnal bract of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	35.69	17.84	7.08**
Initial leaf (Regr.)	1	5.75	5.75	2.28NS
Error	60	151.23	2.52	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 14.83

Table 29. ANOCOVA Effect of night temperature and initial leaf number on length of the second cincinnal bract of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	4.15	2.07	3.92*
Initial leaf (Regr.)	1	0.003	0.003	0.01NS
Error	57	30.15	0.52	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 9.79

Table 30. ANOCOVA Effect of night temperature and initial leaf number on length of the third cincinnal bract of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	3.74	1.87	2.92[NS]
Initial leaf (Regr.)	1	0.40	0.40	0.63[NS]
Error	16	10.28	0.64	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 12.52

Table 31. ANOCOVA Effect of night temperature and initial leaf number on number of cincinnal bracts of H. stricta.

Source	df	SS	MS	F[z]
Temperature	2	0.12	0.06	0.20[NS]
Initial leaf (Regr.)	1	0.13	0.13	0.43[NS]
Error	60	18.65	0.31	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 24.43

Table 32. ANOVA Effect of photoperiod on number of generations of H. stricta per pot.

Source	df	SS	MS	F[z]
Photoperiod	1	2.81	2.81	11.53**
Error	58	14.16	0.24	
Total	59	16.98		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 12.3

Table 33. ANOVA Effect of photoperiod on number of pseudostems developed from senior and junior buds per pot for H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	58.02	58.02	4.01NS
Error	58	840.17	14.48	
Total	59	898.18		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 32.3

Table 34. ANOCOVA Effect of photoperiod and generation on number of shoot developed from top buds for H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	1.68	1.68	1.26^{NS}
Generation (Regr.)	1	0.41	0.41	0.31^{NS}
Phot. x Gen.	1	0.03	0.03	0.02^{NS}
Error	106	141.32	1.33	
Total	109	143.45		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 48.8

Table 35. ANOCOVA Effect of photoperiod and generation on scale leaf number of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	0.21	0.21	1.28
Generation (Regr.)	1	6.93	6.93	42.66**
Phot. x Gen.	1	0.48	0.48	2.97NS
Error	676	109.78	0.16	
Total	679	117.41		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 7.9

Table 36. ANOCOVA Effect of photoperiod and generation on sympodial unit length of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	8.63	8.63	18.56**
Generation (Regr.)	1	28.87	28.87	62.10**
Phot. x Gen.	1	32.02	32.02	68.88**
Error	675	313.78	0.46	
Total	678	383.30		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 28.0

Table 37. ANOCOVA Effect of photoperiod and generation on central branching angle (Y) of H. stricta rhizomes.

Source	df	SS	MS	F[z]
Photoperiod	1	74.95	74.95	0.23^{NS}
Generation (Regr.)	1	9455.96	9455.96	20.84^{**}
Phot. x Gen.	1	118.56	118.56	0.36^{NS}
Error	280	91806.50	327.88	
Total	283	101455.98		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 14.3

Table 38. ANOCOVA Effect of photoperiod and generation on central branching angle (angle in the first generation was not included) of H. stricta rhizomes.

Source	df	SS	MS	F[z]
Photoperiod	1	113.13	113.13	0.93^{NS}
Generation (Regr.)	1	293.62	293.62	2.41^{NS}
Phot. x Gen.	1	13.52	13.52	0.11^{NS}
Error	203	24768.36	122.01	
Total	206	25188.64		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 8.96

Table 39. ANOCOVA Effect of photoperiod and generation on percent senior bud oriented to the right of its parent for *H. stricta*.

Source	df	SS	MS	F[z]
Photoperiod	1	2439.92	2439.92	0.97^{NS}
Generation (Regr.)	1	5.44	5.44	0.00^{NS}
Phot. x Gen.	1	495.92	0.20	0.65^{NS}
Error	363	909592.76	2505.76	
Total	366	912534.05		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 108.1

Table 40. ANOCOVA Effect of photoperiod and generation on number of leaves subtending the inflorescence of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	1.04	1.04	1.71[NS]
Generation (Regr.)	1	21.70	21.70	35.61[**]
Phot. x Gen.	1	3.45	3.45	5.66[*]
Error	112	68.25	68.25	0.61
Total	115	94.43		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 12.4

Table 41. ANOCOVA Effect of photoperiod and generation on peduncle length of H. stricta inflorescences.

Source	df	SS	MS	F[z]
Photoperiod	1	828.38	828.38	18.80**
Generation (Regr.)	1	141.09	141.09	3.20NS
Phot. x Gen.	1	169.79	169.79	3.85NS
Error	66	2908.81	44.07	
Total	69	4048.07		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 19.9

Table 42. ANOCOVA Effect of photoperiod and generation on inflorescence length of *H. stricta*.

Source	df	SS	MS	F[z]
Photoperiod	1	90.36	90.36	7.83**
Generation (Regr.)	1	29.73	29.73	5.42*
Phot. x Gen.	1	8.64	8.64	1.57NS
Error	66	361.91	5.48	
Total	69	490.64		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 16.6

Table 43. ANOCOVA Effect of photoperiod and generation on length of inflorescence + peduncle of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	1465.94	1465.94	26.35**
Generation (Regr.)	1	300.36	300.36	5.40*
Phot. x Gen.	1	255.02	255.02	4.58*
Error	66	3671.82	55.63	
Total	69	5693.14		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 15.7

Table 44. ANOCOVA Effect of photoperiod and generation on length of the last basal sheath + petiole of pseudostems with 6 leaves of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	15238.62	15238.62	88.10**
Generation (Regr.)	1	1141.02	1141.02	6.60*
Phot. x Gen.	1	393.63	393.63	2.28NS
Error	147	25427.84	172.97	
Total	150	42201.13		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 27.8

Table 45. ANOCOVA Effect of photoperiod and generation on length of the last leaf blade of pseudostems with 6 leaves of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	3178.61	3178.61	118.86**
Generation (Regr.)	1	564.11	564.11	21.09**
Phot. x Gen.	1	63.25	63.25	2.37NS
Error	147	3931.11	26.74	
Total	150	7737.08		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 16.7

Table 46. ANOCOVA Effect of photoperiod and generation on the length of the entire pseudostems (vegetative or reproductive) with 6 leaves of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	32336.67	32336.67	106.41**
Generation (Regr.)	1	3309.71	3309.71	10.89**
Phot. x Gen.	1	772.46	772.46	2.54NS
Error	147	44670.35	303.87	
Total	150	81089.20		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 22.3

Table 47. ANOCOVA Effect of photoperiod and initial leaf number on number of weeks to first anthesis from begining of the treatment for *H. angusta*.

Source	df	SS	MS	F^z
Photoperiods	4	40.60	10.15	1.22^{NS}
Initial leaf (Regr.)	1	87.83	87.83	10.53^{**}
Error	25	208.56	8.34	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 17.25

Table 48. ANOCOVA Effect of photoperiod and initial leaf number on number of leaves subtending inflorescences for H. angusta.

Source	df	SS	MS	F^z
Photoperiods	4	3.65	0.91	3.08^{*}
Initial leaf (Regr.)	1	3.38	3.38	11.41^{**}
Error	25	7.41	0.29	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 11.18

Table 49. ANOCOVA Effect of photoperiod and initial leaf number on inflorescence length for H. angusta.

Source	df	SS	MS	F^z
Photoperiods	4	589.19	147.29	2.86^{NS}
Initial leaf (Regr.)	1	163.13	163.13	3.17^{NS}
Error	17	874.36	51.43	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels. CV = 15.96

Table 50. Effect of photoperiod (SD and LD) and initial leaf number on width of apical meristems of H. stricta

Source	df	SS	MS	F[z]
Photoperiod	1	21144.48	21144.48	0.37^{NS}
Initial leaf (Regr.)	1	382572.49	382572.49	6.73^{*}
Phot. x Int. Lf.	1	74504.10	74504.10	1.31^{NS}
Error	8	454927.93	454927.93	
Total	11	933149.02	933149.02	

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels.

Table 51. Effect of photoperiod (SD and LD) and initial leaf number on height of apical meristem of H. stricta.

Source	df	SS	MS	F[z]
Photoperiod	1	1690268.63	1690268.63	46.62**
Initial leaf (Regr.)	1	1669639.61	1669639.61	46.05**
Phot. x Int. Lf.	1	1225084.03	1225084.03	33.79**
Error	8	290047.62	36255.95	
Total	11	4875039.90		

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels.

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